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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 275

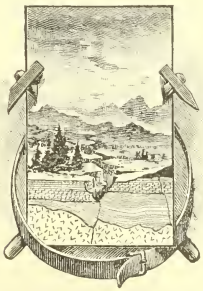
GEOLOGY AND WATER RESOURCES OF ESTANCIA VALLEY, NEW MEXICO

WITH NOTES ON

GROUND-WATER CONDITIONS IN ADJACENT PARTS OF CENTRAL NEW MEXICO

BY

OSCAR E. MEINZER



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MAP OF ESTANCIA VALLEY, NEW MEXICO, SHOWING PHYSIOGRAPHY AND PLEISTOCENE AND RECENT GEOLOGY

LEGEND

PHYSIOGRAPHIC PROVINCE

ANCIENT LAKE BED

- Salt basins
- Clay hill area
- Lake flat
- Littoral zone
- Alluvial slope

PRINCIPAL FORMATION AT THE SURFACE

- Lake sediments and recently deposited clay with precipitates of salt left by evaporating waters. *Boundaries are taken from the township plats of the General Land Office*
- Wind-blown clay
- Lake sediments
- Beach materials and alluvial deposits with sand dunes on the east side
- Alluvial deposits

Boundaries are approximate

GEOLOGY AND WATER RESOURCES OF ESTANCIA VALLEY, NEW MEXICO.

By Oscar E. Meinzer.

INTRODUCTION.

LOCATION AND AREA.

Estancia Valley lies near the geographic center of New Mexico, south of Santa Fe and east of Albuquerque. Its drainage basin

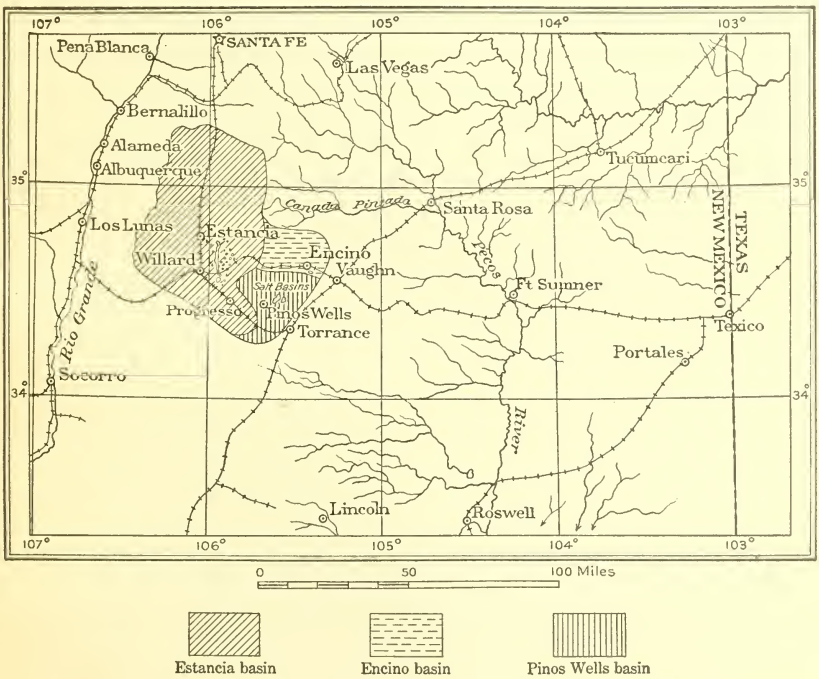


FIGURE 1.—Map showing location of Estancia, Encino, and Pinos Wells basins.

forms a depression with no outlet, having a maximum extent of about 65 miles north and south and 40 miles east and west, and includes an area of about 2,000 square miles (fig. 1).

GEOGRAPHIC RELATIONS.

On the west Estancia Valley is separated from Rio Grande Valley by a mountain wall; on the east it is bordered by a maze of hills which divide it from the upland that slopes toward the Pecos Valley and from the Encino and Pinos Wells basins; on the north it rises gradually until it ends abruptly as a plateau overlooking the valley of Galisteo Creek, which flows westward into the Rio Grande; on the southwest it is terminated by a mesa; and on the southeast, where it is hemmed in between the mesa and the hills, it is separated by a low divide from the Pinos Wells Basin.

DEVELOPMENT.

This valley has long supported a sparse population. Nestled in the western foothills, remote from any city or railroad, the Mexican villages of Chilili, Tajique, Torreon, Manzano, and Punta de Agua have for generations led a peaceful but primitive existence, their inhabitants depending for a livelihood chiefly upon their flocks of sheep. Moreover, planted here and there upon the broad, level expanses of the valley proper are isolated establishments which have been the homes of independent and prosperous ranchers, most of whom are Mexicans.

But within the past decade a great change has taken place. Two railways have been built—the New Mexico Central Railroad, which traverses the entire length of the valley, and the "Belen cut-off" of the Atchison, Topeka & Santa Fe Railway, which crosses its southern part. Hundreds of homesteaders have come to take possession of the land, and eight villages have sprung up along the railways.

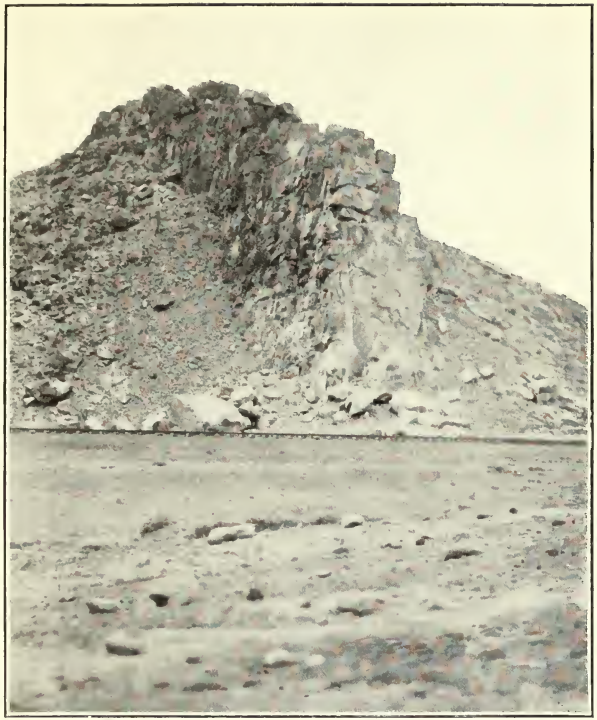
FIELD WORK.

Insufficient rainfall during recent years has caused crop failures and has created an urgent demand for an investigation of the feasibility of irrigating with ground water. In response to this demand, and for the purpose of classifying the land under the enlarged homestead act, an examination of the valley covering a period of six weeks was made by the writer in the summer of 1909. The time spent was not sufficient to make a complete investigation, hence attention was directed especially to the more practical phases of the problem. In August, 1910, several days were spent in the Encino and Pinos Wells basins.

PHYSIOGRAPHY.

MOUNTAINS, HILLS, AND MESAS.

West of the valley is the Manzano Range, which extends for 30 miles as an unbroken mountain wall and forms a sharp divide between the Estancia and Rio Grande basins. This range culminates in a



A. "GATEWAY" THROUGH DIKE NORTH OF ESTANCIA VALLEY.

See page 9.

B. CANYON IN MESA JUMANES.

See page 9.

series of peaks, the loftiest of which—such as Manzano Peak, Capillo Peak, and Mosca Peak—reach altitudes of more than 9,000 feet above sea level and more than 3,000 feet above the valley. The range supports a forest of large pine trees, most of which are included in the Manzano National Forest, and along its eastern base is a broad, irregular belt of foothills partly covered with smaller timber.

At the northwest corner of Estancia Valley are South Mountain and the San Pedro Mountains, two isolated masses which include a number of peaks that reach altitudes of more than 8,000 feet above sea level. Between South Mountain and the north end of the Manzano Range, a distance of nearly 15 miles, the moutain wall is interrupted, the divide between the Estancia and Rio Grande basins here being formed by a more or less hilly upland tract through which the not yet completed railway from Moriarty to Albuquerque finds a low pass.

North of the San Pedro Mountains is a still larger mountain mass, known as the Ortiz Mountains. North of the Manzano Range and separated from it by Tijeras Canyon is another lofty range, known as the Sandia Mountains. Both Ortiz and Sandia mountains lie entirely outside the Estancia Basin.

The valley is bordered on the northeast by a mesa whose margin is dissected into rugged and fantastic erosion forms. Cañada Colorada (Red Canyon), one of the largest gorges that has been carved out of this mesa, is picturesque and imposing. Farther south are the Hills of Pedernal, whose somber gray hue contrasts strongly with the vivid colors of the escarpment of the mesa and the Red Canyon. Back of these hills, outside of the Estancia drainage basin, stands Pedernal Mountain. The hills that inclose the valley on the southeast are lower and more subdued.

From the center of the valley northward the surface rises gently up to a point where the plain ends abruptly in an escarpment, so that, seen from the north, Estancia Valley is a mesa which forms the south boundary of the Galisteo Creek drainage basin. Here the tributaries of the creek are actively eroding and are thereby gradually shifting the divide southward. A short distance north is a huge igneous dike, which stands in prominent relief as a result of the denudation of the softer rocks through which it projects. This dike has evidently hindered the erosive attack on the north end of Estancia Valley. The gap in the dike through which the drainage passes has long been utilized as an approach to Estancia Valley, and the New Mexico Central Railroad now enters through this "Gateway." (See Pl. II, *A*.)

On the southwest the valley is terminated abruptly by the Mesa Jumanes, whose escarpment, 500 feet high, forms an imposing physiographic feature (Pls. II, *B;* III, *B*). Between the Mesa Jumanes and the Manzano Range is a pass through which the Atchison, Topeka & Santa Fe Railway finds an exit westward.

To the southeast the valley becomes constricted between the Mesa Jumanes, which forms its southwestern flank, and the hills which border it on the northeast. This constricted belt extends a considerable distance and eventually opens into the Pinos Wells Basin. The New Mexico Central Railroad passes through it and leaves the Estancia drainage basin at probably the lowest point on the basin's rim.

ALLUVIAL SLOPES AND ARROYOS.

A gently sloping plain, formed by sediments washed out from the mountains, extends from the mountainous border toward the flat center. The gradient of this plain is not great, but is sufficient to be perceptible, and in general it decreases toward the center of the valley. Over wide tracts the surface is exceedingly even, but, taken as a whole, the evenness is broken by many irregularities, most of which can be grouped into two classes—rock hills and arroyos.

At a number of localities isolated masses of hard rock project prominently above the smooth plain, which surrounds them almost as a sea surrounds a rocky island. One of the most conspicuous of these masses is the unique butte known as Cerrito del Lobo.

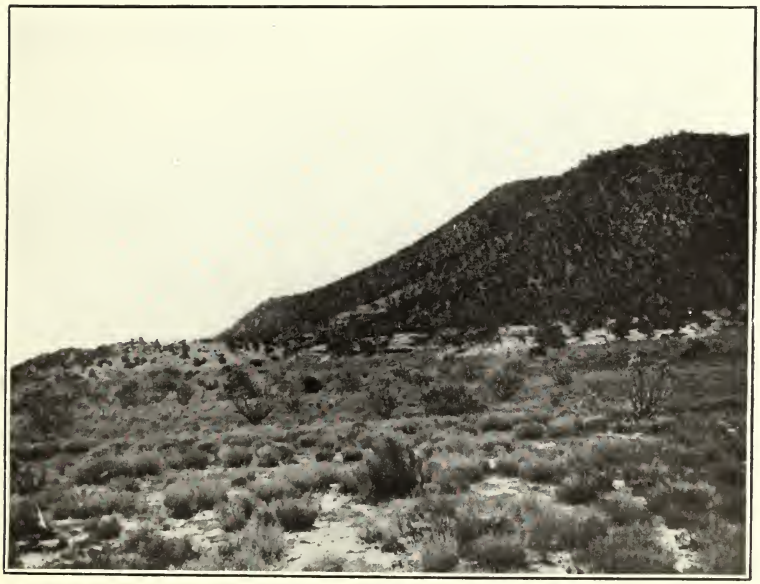
The arroyos, or "draws," constitute an important feature of this part of the valley. Most of them have their origin in canyons that debouch from the mountainous border, whence they traverse the sloping plain, all converging toward the center of the valley. They have no great tendency to join each other, but many of them continue in straight and nearly parallel courses for long distances. In general they are deepest near the mountains, where the largest may be bordered by impressive cliffs nearly or quite a hundred feet in height, and become shallower toward the basin until ultimately they disappear upon the central flat. Most of them are broad, several being more than a mile wide. Their flat bottoms are rarely trenched by gullies except in the upper courses, for they are stream channels rather than valleys through which stream channels meander. Generally speaking, they carry no permanent streams, but form avenues for the escape of storm waters, and are built on a scale commensurate with the volume of the torrential floods which they must periodically accommodate. These floods usually disappear before they reach the central flat, and in disappearing they leave the sediment with which they were laden. Thus the arroyo bottoms are at present being built up rather than cut down.

ANCIENT LAKE BED.

The central portion of the valley is for the most part flat (Pl. III, *A*), and there is good evidence that it was once the bed of a lake, a fact which has been noted by Keyes in a brief paper on "Ephemeral

A. LAKE FLAT.

See page 10.



B. MESA JUMANES, SHOWING LANDSLIDING.

See page 13.

Lakes,"[1] in which he states that "the Sandoval bolson, south of Santa Fe, contains traces of a comparatively recent lake of considerable size." At the margin of this ancient lake bed are beach ridges and other shore features, which, although not obtrusive, are distinct, and occur on all sides at the same vertical horizon. (See Pls. IV, *B;* V, *A* and *B;* XIII, *C.*) The belt within which shore features exist (which will be designated the "littoral zone") forms the inner boundary of the "alluvial slopes" and the outer boundary of the "lake flat." In Plate I the littoral zone and the lake flat are represented as occupying about 180 square miles each, but it should be understood that the boundary between these two areas is very arbitrarily drawn. For the sake of convenience, though at the sacrifice of logical arrangement, the shore features are described under the heading "Geology."

SALT BASINS AND CLAY HILLS.

Although most of the central area of the valley is flat, one portion, forming a region of considerable extent (roughly estimated as 85 square miles), contains irregular clay hills associated with sharply bordered depressions containing salty mud flats, the whole forming a strange labyrinth (Pls. VI, IX, and X), the full discussion of which will be found under the heading "Geology."

GEOLOGY.

ROCK FORMATIONS.

METAMORPHIC AND IGNEOUS ROCKS.

Manzano Range.—The core of the Manzano Range consists of a complex of schists and quartzites, with associated masses of granite and other igneous formations. These rocks are supposed to have been brought to their present elevated position by a grand faulting movement near the close of the Cretaceous period. Because of their resistant character and nearly vertical dip they form sharp ridges and peaks.

The east side.—On the east side of the central and southern portions of the valley igneous and metamorphic rocks are also exposed. Pedernal Mountain, which lies in the northeast part of T. 7 N., R. 12 E., consists of flint-like quartzite in which considerable schistosity has been developed. The Hills of Pedernal lie west of this mountain and form a belt several miles long (chiefly in T. 7 N.) consisting of low but rugged peaks that rise abruptly above the level table-land that borders them on the north and the undulating upland on the south. Like Pedernal Mountain, they consist mainly of quartzite. They have been described as formed "by an uplift of quartz-bearing rock, the metamorphism produced by this intru-

[1] Keyes, C. R., Ephemeral lakes: Am. Jour. Sci., 4th ser., vol. 16, 1903, p. 377.

sion being evidenced by a broad band of hornblende schist along the western base of the hills." [1] They appear to belong to the same formation as the schists and quartzites in the Manzano Range and probably have similar structural relations to the contiguous rocks.

Cerrito del Lobo, the previously mentioned isolated butte in the eastern part of the valley, is an outlier of the same quartzite formation. Across it, with a north-south trend, runs a breccia zone that has been weathered more rapidly than the quartzite through which it passes, thus giving the butte a bilobate profile that can be seen miles away. This bilobate feature also characterizes some of the Hills of Pedernal.

South of the Hills of Pedernal the eastern wall of the basin is formed by a broad, undulating upland, which is for the most part grass-covered, but in which red granite is exposed at numerous points and schist and quartzite are found. These rocks have also been encountered in wells.

The northwest side.—South Mountain and the San Pedro Mountains, as well as the Ortiz and other mountains to the north, consist of cores of igneous rock supposed to be laccoliths formed by great intrusions of lava near the close of the Cretaceous period.[2] The dike through which the "Gateway" passes (Pl. II, *A*) is a member of this great intrusive system.

CARBONIFEROUS ROCKS.

Outcrops on the west side.—A formation consisting of thick beds of massive gray limestone with a few relatively unimportant layers of sandstone and shale extends eastward from the metamorphic and igneous rocks of the Manzano Range, forming a rugged foothill belt. In general, it dips gently away from the mountains and passes beneath younger strata. In Abo Canyon, which cuts across the low southern end of the Manzano Range, west of Mountainair, G. B. Richardson, who in 1905 made a reconnaissance along the line of the Belen cut-off, observed a thickness of about 500 feet, mostly of massive limestone, containing abundant Carboniferous fossils at some horizons. The formation is also well exposed in the canyons back of the village of Manzano and elsewhere.

Red beds several hundred feet thick, consisting chiefly of fine-grained sandstone with some shale, occur farther east and evidently lie above the limestone. They were observed by Richardson in the vicinity of Abo Canyon in a north-south escarpment and are exposed farther north in a similar position and for several miles form the south bluff of Arroyo Mesteño (Manzano Draw).

[1] Johnson, D. W., Notes of a geological reconnaissance in eastern Valencia County, N. Mex.: Am. Geologist, vol. 29, 1902, p. 87.

[2] Johnson, D. W., Geology of the Cerrillos Hills, N. Mex.: School of Mines Quart., vol. 24, 1903, pp. 463–471.

South of Willard (SE. ¼ sec. 31, T. 4 N., R. 9 E.) the escarpment of Mesa Jumanes shows the following succession of essentially horizontal strata:

Section in escarpment of Mesa Jumanes.

	Feet.
Limestone, dark gray	50
Sandstone, gray, or buff, friable	300
Sandstone, etc., red	10
Gypsum	100
Talus.	

There is good evidence that this series lies stratigraphically above the red beds exposed along Arroyo Mesteño and elsewhere. Its age is fixed by several species of upper Carboniferous fossils found by Richardson in the capping limestone.[1]

Mesa Jumanes is in places bordered by chaotic heaps of talus that appear to have been formed by landslides that probably resulted from the basal position of the thick bed of soft gypsum (Pl. III, *B*).

Well sections on the west side.[2]—The following data concerning wells bear on the occurrence of the above-described series in the western part of Estancia Valley:

Section of railway well at Mountainair.

[Surface elevation: 6,486 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, etc.	20	20
Clay and gravel	20	40
Lime and dry gravel	30	70
Red rock (i. e., hard red clay)	110	180
Blue-gray shale	20	200
Red rock (hard clay)	83	283
Blue-gray shale rock (water at 295 feet)	27	310
Red clay and small dry gravel	20	330

Section of Atchison, Topeka & Santa Fe Railway well at Willard.

[Surface elevation: 6,100 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Light-red clay and gravel	35	35
Coarse gravel, etc., containing water	17	52
Light-red clay and gravel	78	130
Coarse gravel, etc., containing water	22	152
(?)	81	233
Sand, gravel, etc.	79	312
Red sand rock, entered	128	440

[1] Lee, Willis T., and Girty, G. H., The Manzano group of the Rio Grande valley, New Mexico: Bull. U. S. Geol. Survey No. 389, 1909, p. 21.

[2] Sections furnished by Atchison, Topeka & Santa Fe Railway Co.

In the test well recently sunk 4 miles east of Estancia (SW. ¼ sec. 10, T. 6 N., R. 9 E.) a formation described by the driller as "red hematite iron ore" was found between the depths of 225 and 525 feet, and red sandstone between 577 and 707 feet.

In the well of H. C. Williams, 2½ miles south of Estancia (NE. ¼ sec. 26, T. 6 N., R. 8 E.), soft gray sandstone was encountered between the depths of 233 and 303 feet, below which is red clay that was entered about 15 feet.

Between Mountainair and Arroyo Mesteño several wells penetrate dense red sandstone, while red shale is reported in numerous wells on the west side almost to the north end of the valley.

Outcrops and well sections on east side.—A similar series of gypsum, red and buff sandstones, red shale, and gray limestones exists on the east side of the valley, and light-colored sandstone occurs in a succession of low outcropping ridges north of Lucia for 15 miles.

North of the Hills of Pedernal the east wall of the basin is formed by relatively level table-land, which is terminated on the southwest by an escarpment that appears, for at least a part of its extent, to follow a fault line. The formations that underlie the table-land are exposed in this escarpment and also in Cañada Colorada (Red Canyon) and a number of smaller canyons. Wherever they were observed, they lie nearly horizontal and consist of beds that bear a general resemblance to the Carboniferous formations on the west side. In the vicinity of Cañada Colorada there is a basal hard, gray limestone, overlain by a brownish red or chocolate-colored massive limy formation, upon which rests a second hard, gray limestone, somewhat over 50 feet of strata belonging to the three formations being here exposed. Above the second limestone a thickness of considerably more than 100 feet of sandstone is exposed, while the cap rock, at the top of the cliff, consists of less than 5 feet of indurated gray limestone. The sandstone, which is prevailingly light yellow, is rather soft and weathers into fantastic, castellated forms. It shows abundant cross-bedding and ripple marks. Farther northeast is a series of soft red shale and sandstone, which is white at the top owing to the presence of limy material. This series is at least 100 feet thick and appears to rest on the cap rock that outcrops at the top of the escarpment.

Immediately southwest of the escarpment and dipping sharply away from it is a series of rocks consisting of gypsum, red beds, and sandstone, somewhat resembling the series that outcrops in Mesa Jumanes. Between the escarpment and the valley proper is an upland belt in which there are numerous exposures of limestone, sandstone, and other formations. These strata generally slope toward the valley, but their dip differs greatly in different localities and in some places takes the opposite direction. In certain localities (as in secs. 26 and 27, T. 11 N., R. 10 E.) the dip differs greatly within

short distances, and fracturing and slicken-sided surfaces (as in SE. ¼ sec. 35, T. 10 N., R. 9 E.) also show that violent deformation has taken place in this region.

At Lucia the following section is reported by the Atchison, Topeka & Santa Fe Railway Co.:

Section of railway well at Lucia.

[Surface elevation, 6,177 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Loose gravel	20	20
Cemented gravel	(?)	(?)
(?)	(?)	100
Red sand	10	110
Coarse gravel	10	120
Lime gravel (water)	5	125
Hard white sandrock	5	130
Gray lime	5	135
Red clay	10	145
Lime and clay	5	150
Gray lime	14	164
Red clay	26	190
Gray lime	15	205
Lime and clay	15	220
Gray lime	10	230
Lime and clay	15	245
Red clay (water)	15	260
Fine red sand	25	285
Red clay	30	315
Gray lime (water in vein)	5	320
Dark-gray limestone	25	345
Black shale, entered	5	350

Immediately west of Lucia the railway cuts through light-colored sandstone, which also outcrops in this vicinity. In drilling the well of E. Moulton, in Lucia, this bed of sandstone was found between the depths of 16 and about 75 feet, below which was encountered a bed, about 15 feet thick, of soft white material (possibly gypsum), and then red clay and sand, in which the well ends. J. E. Pauley, a driller, reports other wells in the region north of Lucia which pass through light-colored sandstone and enter red clay and sand.

CRETACEOUS ROCKS.

In the region north of Estancia Valley there is exposed a thick series of Cretaceous strata, chiefly shale and sandstone, to which geologists have given considerable attention. It is represented in the areas bordering South Mountain and the San Pedro Mountains and in the north rim of Estancia Valley. It no doubt occurs beneath the north part of the valley, but there is no proof that it extends far south, for the section of the test well 4 miles east of Estancia and other well sections here given indicate that it is absent in at least much of the southern part of the valley.

VALLEY FILL.

AGE AND CHARACTER.

The hard rock floor of Estancia Valley is covered by deposits that may be grouped under the general term "valley fill." Nearly all these sediments originally came from the highlands that border the valley and are the product of thousands of years of weathering and denudation. The erosive processes which have carved the canyons and given form to the serrate peaks have at the same time supplied the material that has accumulated in the lowlands as the valley fill.

These sediments derived from the mountains were chiefly washed by storm waters into the valley, where they lodged to form the deposits of the alluvial slopes, or were carried into the ancient lake, to settle quietly on its bottom or to be worked over by the waves. Some of these sediments have more recently been picked up and driven about by the wind. The deposits of salt in the salt basins are also of recent formation. The valley fill can therefore be classified as follows:

4. Precipitates from solution: Salt and gypsum beds.
3. Wind deposits: Clay hills and sand dunes.
2. Lake deposits: Stratified sediments and beach materials.
1. Alluvial deposits.

All these deposits are geologically young. In general, the oldest are the alluvial deposits, the next in age the lake deposits, and the youngest the wind deposits and salt beds.

The age of the lake deposits is the most definitely fixed, for without doubt this lake was synchronous with Lake Bonneville, in Utah, and other ancient lakes of the arid West, which are unanimously and with good reason correlated with the cold, humid glacial period. The lake deposits may therefore be considered Pleistocene in age. The stratified sediments and beach materials are of about the same age, for at the time that the coarser materials along the beach were continually being handled and rehandled by the waves finer sediments were settling quietly in areas more remote from the shore.

The alluvial deposits have a much wider range in age. Part of them are coeval with the lake deposits, part are more recent; some, indeed, are very recent, but there is evidence that most of them were laid down in their present position before the advent of the lake, and hence belong chiefly to the late Tertiary or early Pleistocene.

The wind deposits come within the late Pleistocene and Recent periods, for the dune sand was chiefly supplied by the lake and the clay deposits were all formed since the lake dried up. The sand has, on the whole, been buffeted about by the wind longer than the clay.

WORK OF THE STREAMS.

DISTRIBUTION OF THE ALLUVIAL DEPOSITS.

The bulk of the valley fill consists of alluvial deposits; that is, of materials laid down by the streams and not rehandled by any other agency. Such deposits underlie the broad belt comprising the alluvial slopes (Pl. I), are interbedded and intermingled with lake deposits in the littoral zone, as can be seen in many natural and artificial exposures, and probably occur at no great depths below the lake sediments in the lake flat and clay hill area. Their relation to the lake deposits can, however, be best understood after those deposits have been described.

The alluvial material is much thicker in some localities than in others. If the interpretations of the well sections are correct, the total thickness of the valley fill is 312 feet at Willard, 225 feet in the test wells 4 miles east of Estancia, and 233 feet in H. C. Williams's well south of Estancia. L. Knight's deep well (in the NE. $\frac{1}{4}$ sec. 1, T. 5 N., R. 8 E.) was carried to a depth of 240 feet without encountering rock. In many parts of the valley, however, especially on its east and west margins, the alluvium is much thinner and rock crops out.

ORIGIN OF THE ALLUVIAL DEPOSITS.

The alluvial deposits were laid down by streams which were probably intermittent and exceedingly irregular in their flow, depending then, as now, chiefly on the sudden and capricious visitations of heavy local storms. The work of these streams was correspondingly capricious and variable; at one place they eroded, only to deposit a little farther on the load which they thus picked up; at one place they left behind coarse gravel, and at another they laid down only fine silt. The same locality was at different times subjected to all these conditions and, moreover, by the frequent changing of the courses of the streams, was at one time an arroyo and at another an interstream area. It is therefore not surprising that the alluvial deposits consist of heterogeneous beds which have little continuity or regularity, and that two wells in the same locality should have quite different sections.

CHARACTER OF THE ALLUVIAL DEPOSITS.

Most of the alluvial material consists of clay, with which are associated pebbles and bowlders of different sizes and composition. In general the pebbles and bowlders decrease both in size and abundance from the mountain borders, where bowlder beds with little or no clay may occur, toward the central portion of the valley, where clay virtually free from pebbles may be found. But though coarse materials form a larger proportion of the mass in the regions near

the mountain than in the interior, yet well sections furnish abundant proof that beds of clean gravel and sand occur in the very heart of the valley. The composition of the pebbles depends on the kind of rocks that constitute the uplands and the resistance of these rocks to weathering and wear. On the whole pebbles of limestone are by far the most numerous, because this rock is well represented in the uplands, especially on the west, and is also resistant in character.

The alluvial deposits present two or three types which differ in color, cementation, and position. The type most commonly encountered near the surface has a pink hue. It is only slightly indurated, but contains so much cementing material that wells sunk into it require no curb. Pink deposits are shown at the north end of the valley, where they have been exposed by erosion on the tributaries of Galisteo Creek. The igneous bowlders and the direction of the cross-bedding in this locality show that the deposits were derived from higher ground to the north, which has since been eroded away.

Deposits of a second type have a dull gray color and are cemented into a conglomerate, which is locally known as "concrete." Their gray color is due to the large amount of calcium carbonate and other cementing material they contain and also to the greater abundance in them of dark gray limestone pebbles. Gray conglomerate crops out in the cliff on the McIntosh ranch, in the region west of Willard, and elsewhere, and is also found in many wells at levels below the pink alluvium.

Deposits of a third type may be discriminated in which the cementing process has gone so far that the formation has lost the appearance of alluvium and has become a sort of massive concretionary limestone, or caliche. Limestone of this type lies near the surface over a large area in the vicinity of Cedarvale, at the southern extremity of the valley, and in the region south of Otto, where it forms a ridge through which the railway cuts (sec. 30, T. 10 N., R. 9 E.).

WORK OF THE LAKE.

SIZE OF THE LAKE.

At its period of greatest extension the lake that occupied the central portion of the valley was about 35 miles long and 23 miles wide and had an area of about 450 square miles. Its maximum depth at this period was almost 150 feet, and its shore line, which nearly coincides with the 6,200-foot contour, was about 150 miles long. If this lake were now in existence the villages of Estancia and Willard would be 100 feet under water; McIntosh and Progresso would also be submerged; Moriarty and Lucia would virtually be lake ports; and Stanley, Mountainair, and Cedarvale would be inland towns. The higher ground which surrounded the lake has been explored every-

where, but no outlet channel has been found, and it is therefore certain that the lake had no outlet and that its water was salt.

The theory of the existence of an ancient lake in the valley is based on the presence of shore features and lake sediments.

SHORE FEATURES.

Sea cliffs, terraces, beaches, beach ridges, spits, and bars are found within the littoral zone on all sides of the lake flat, at altitudes between 6,100 and 6,200 feet above sea level.

CLIFFS AND TERRACES.

A distinct sea cliff occurs southwest of Lucia (about NW. ¼, sec. 11, T. 4 N., R. 10 E.), and another cliff marks the exposed end of the land that projects eastward between Arroyo de Torreon and Arroyo Mesteño (sec. 9, T. 5 N., R. 8 E.). Wave erosion is well shown in many places, notably on the sandstone outcrops southwest of Dunbar's ranch (T. 6 N., R. 10 E.).

The prominent escarpment northwest of Willard coincides with the shore line, but whether it was formed by the lake is uncertain. There is also, perhaps, ground for doubt as to the origin of the cliff at the McIntosh ranch, directly northwest of the village of McIntosh, and of the cliff immediately northwest of Antelope Springs. (See Pl. V, *B*.) Both of these coincide with the shore line, and the McIntosh cliff at least has been scoured by water and strewn with beach materials.

There are many terraces, more or less distinct and more or less intimately associated with beach ridges. Those in the vicinity of the cliff between Arroyo de Torreon and Arroyo Mesteño and those on the south margin of Arroyo de Torreon, near its mouth, will serve as examples, but others equally distinct occur in many localities.

BEACH RIDGES.

North and northeast of Lucia several prominent beach ridges (as in SE. ¼ sec. 4, T. 5 N., R. 11 E.) persist for considerable distances. They also extend, somewhat obscured by drifting sand, parallel to the east shore in T. 6 N., R. 11 E.; T. 7 N., R. 10 E.; T. 8 N., R. 9 E.; and between Lucia and Progresso. They are found in the embayment of Arroyo Mesteño (as in sec. 21, T. 5 N., R. 8 E.), and extend from the mouth of this arroyo to the mouth of Arroyo de Torreon. North of Arroyo de Torreon they occur almost continuously nearly to the north end of the lake (for example, in sec. 21, T. 6 N., R. 8 E., and sec. 23, T. 8 N., R. 8 E.). In short, beach ridges, large and small, are abundant throughout the littoral zone on both sides of the lake flat. They are, however, interrupted by the mouths of the arroyos, and are so generally absent at the north end (north of Arroyo del Cibolo, or Buffalo Draw) that the position of the shore line there is uncertain.

SPITS.

North of Lucia there are two large spits. The one farthest north, shown in Plate IV, *B*, is a definite gravelly ridge several rods in total width and about 10 feet high. It extends northeastward from the north end of a low sandstone ridge over a flat plain for a distance of about 1½ miles and terminates abruptly. It was evidently formed by currents which swept northward along the west side of the ridge and thence northeastward into an open sea. The south spit is similar in character and origin. Several smaller spits were observed in other localities.

BARS.

Perhaps the most typical features of the ancient lake bed are the bars built across the mouths of the arroyos. Most of these bars are interrupted by narrow gaps cut by storm waters discharged through the arroyos, but in several small ravines no such gaps have been cut and the natural dams remain unimpaired.

The largest bar is found at the east end of the great eastern embayment. It is about 15 feet high, trends approximately S. 30° E., and persists for several miles unbroken except at the gap which forms the outlet of the arroyo. (See Pl. XIII, *C*.)

Another prominent feature of this type is the remarkably wide embankment thrown across the mouth of the large arroyo south of the railroad west of Willard (T. 4 N., R. 8 E.). On the upstream side it ends abruptly with a steep bank like a normal bar or beach ridge, but on the lakeward side it extends for an indefinite distance, eventually merging with the lake flat. The gap which forms the outlet of the arroyo is a ravine approximately 20 feet deep, 20 feet wide at the bottom, and half a mile long.

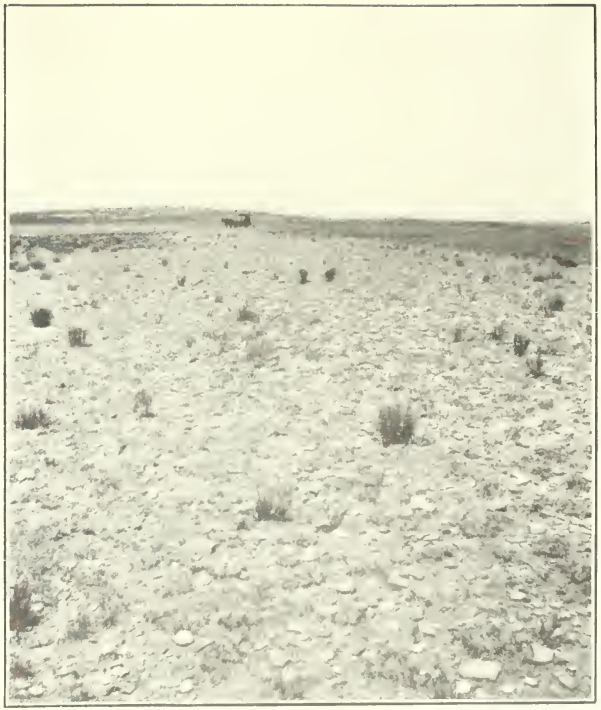
Across the flat expanse of the first large arroyo northwest of the railway are thrown a series of three or more bars, all of which have gaps near their southeast ends. They occur near the mouth of the arroyo, north of the township line (sec. 33, T. 5 N., R. 8 E.).

Another notable bar is in the eastern embayment (sec. 34, T. 6 N., R. 11 E.), and another lies southwest of Antelope Spring, shutting in a ravine that runs east and west between sec. 22 and sec. 27 in T. 7 N., R. 8 E. Plate V, *A*, is a view of this bar from the south and shows the small gap at its south end. Just south of the Arroyo de Torreon is still another bar built across the mouth of a small ravine also having a gap at the south end.

Most of the gaps are post-lacustrine drainage channels like the one in the large bar first described. Some of the gaps, however, are probably places where the bars were never completed. A gap would be formed where a spit projected from one side of an arroyo nearly, but not quite, to the other. The gap in the bar last mentioned may be

A. WIND-DEPOSITED CLAY.

See page 45.



B. SPIT NORTH OF LUCIA.

See page 201.

A. GAP IN BAR NEAR ANTELOPE SPRING.

See page 20.

B. CLIFF FORMING ANCIENT SHORE LINE NEAR ANTELOPE SPRING.

See page 19.

of this kind. Such a gap would serve as an outlet for the drainage and might be deepened and widened by erosion.

A few of the bars built athwart the mouths of small ravines are not broken by gaps. Northwest of Willard (sec. 34, T. 5 N., R. 8 E.) such a bar impounds the storm waters, forming a small lake after heavy rains (Pl. I). Another such bar lies east of McIntosh, near the southeast corner of T. 8 N., R. 9 E. Here a small ravine is obstructed by a high embankment that suggests an artificial dam or a railway fill.

ESTUARIES.

The bars prove that the broad flat-bottomed arroyos were in existence at the time the lake was present. How far up these arroyos were submerged can be inferred only from the topography. During the highest stages of the lake the water must have extended into many of them for considerable distances, forming numerous bays which resembled estuaries. When the lake receded, the water was drained from the arroyos and, except for the rocky islands that appeared in the east, the shore line became much more regular. The flatness of the arroyo bottoms may in part be due to sedimentation during the lake epoch. The gaps in the bars and the gullies that here and there indent the valley sides are practically the only marks of stream erosion made in the lower courses of the arroyos since the departure of the lake.

STAGES INDICATED BY SHORE LINES.

The littoral zone, within which lie the terraces, beach ridges, and other shore features, ranges in width from less than a mile to several miles, but is commonly between 1 and 2 miles wide. Its vertical range is about 100 feet, for it lies between 6,100 and 6,200 feet above sea level. The most prominent features occupy an intermediate position in the zone. The lowest are generally small but distinct; the highest are vague and elusive. As one goes out toward the alluvial slopes from the level and monotonous lake flat the eye is prepared to catch the slightest irregularity, and the first small terraces and ridges invariably force themselves upon the attention. These are quickly followed by much larger features, which may at first appear to mark the ultimate extension of the lake. Upon going farther, however, it becomes evident that the outermost shore line has not yet been reached, for other beaches, which are much smaller and more vaguely defined, come into view. Still farther back all signs of wave work are lacking, and it is manifest that the boundary of the lake has been crossed.

The various shore features were not formed at the same time, but record levels at which the lake stood at different times. The level of

a lake with no outlet is constantly fluctuating, for it is a function of rainfall on the one hand and of evaporation on the other, both of which are varying factors. Thus, when Lake Sevier, in Utah, was explored in 1872 it covered an area of about 188 square miles, but in 1880 it had so nearly dried up that one could walk across its beds;[1] and still more recently, in spite of the increasing amount of water diverted for irrigation from Sevier River, which is its sole tributary, it has refilled until it is again a lake of considerable size. Similar fluctuations have taken place in the level of Great Salt Lake within the relatively brief period in which records have been kept.

Yet even lakes which have no outlet are likely to remain at approximately one level long enough to impress distinct shore lines upon the sides of the basins that contain them. Thus, Lake Sevier has built at its north end a beach ridge comparable in size to the beach ridges of the ancient lake here described.

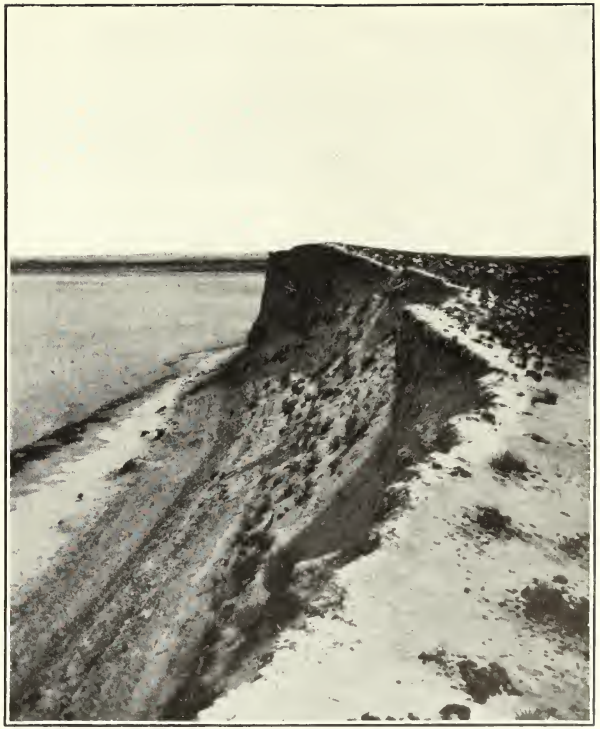
Lake Estancia, no doubt, had many fluctuations, the general history of which could perhaps be ascertained by a minute study of shore lines and by the correlation of lake deposits. The cursory examination that was made indicates that the lake stood at its highest level for only a brief time; that it remained a much longer time at somewhat lower levels, which did not, however, greatly diminish the water area; and that it finally shrank to lower and lower levels until it became too small and too shallow to form shore features that can at present be discerned. In the vicinity of Estancia the innermost shore line observed passes through the western part of the village and east of Estancia Spring.

SIZE OF LAKE AND SIZE OF SHORE FEATURES.

Shore features are the work of waves and currents, and these are produced by the wind. But in order to produce large waves the water must be so deep that the waves will not be dissipated by friction on the bottom, and it must spread uninterruptedly over a large area, so that the winds will have a long sweep. Thus, in storms of the same magnitude, the waves on a large lake will be enormous when compared with those on a pond, but small when compared with the mighty swell of the ocean. If other things had been equal the shore features would be largest at the outermost shore line and would be progressively smaller inward. To the extent that this is not true it must be inferred that the time during which the lake stood at the different levels was not equal. When the lake stood at the level necessary to produce the most pronounced shore features it had shrunk but slightly from its maximum size. When it became smaller it built smaller shore features, and finally it became so constricted and shallow that little wave work was done.

[1] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 224 et seq.

A.



B

CLIFF SURROUNDING A SALT BASIN.

Showing lake sediments overlain by wind-deposited clay. See page 23.

Broadly considered, the shore features in Estancia Valley are commensurate with the size of the ancient lake. They are tiny in contrast with those of the much larger ancient Lake Bonneville, but they compare in size with those of the smaller Lake Sevier.

EFFECT OF PREVAILING WINDS.

A decision as to which side of the lake shows the most vigorous wave work depends somewhat on the interpretation of the cliffs that extend along the west coast. The terraces, beach ridges, spits, and bars are perhaps best displayed on the west side, between Arroyo del Cibolo (Buffalo Draw) and Arroyo Mesteño (Manzano Draw), but this superior distinctness is due partly to the fact that many of the features on the east side, although perhaps larger, have their character obscured by drifting sand. Some of the most conspicuous features are found in the eastern embayment, where, no doubt, large waves were formed by the free sweep of the west winds, but features perhaps equally prominent are found along the southwestern coast. Shore features are not of impressive size at the south end of the lake and are almost undiscernable at the north end.

On the west side there is little sand, but on the east side sand occurs in large quantities—a difference probably due, in part, to the prevalence of westerly storm winds.

LAKE DEPOSITS.

BEACH MATERIAL.

Most of the material constituting the beaches, beach ridges, spits, and bars is gravel. The pebbles are water worn and many of them are covered with a gray coat of lime. The best exposures of beach material are found in the gaps that have been cut through the bars.

STRATIFIED SEDIMENTS.

Except for the salt basins and clay hills, the area within the shore zone is flat (Pl. III, *A*); but the salt basins (Pl. I) are excavated to depths of 10 to 20 feet in the material of this plain, and their sides are generally steep and thus expose the strata to good advantage. Wells have also been dug and are usually left uncased, showing the materials through which they extend. Moreover, many cellars and dugouts have been made, most of which likewise remain unlined. Ample opportunity is therefore afforded to examine the formation which immediately underlies the plain. This formation is totally different from that which underlies the alluvial slopes. It is perfectly stratified, consisting of innumerable thin layers lying one upon another, each layer traceable for an indefinite distance. It is precisely the kind of deposit which would be formed at the quiet bottom of a large body of standing water and which could be formed in no

other manner. It was observed in many exposures, natural and artificial, and in widely separated localities. It is practically coextensive with the lake flat and clay hills area and can be seen wherever there is a salt basin, a dug well, a cellar, or any other excavation. It is shown in Plate VI, *A* and *B*, Plate VII, *A*, and Plate VIII, *A*; but none of these pictures do full justice to the delicate lamination displayed in fresh cuts. Clay or shale constitutes the bulk of the material, but layers of sand were also noted, and beds of grit and fine gravel were observed near the outer margin of the lake flat.

The following is a generalized section of the strata in a large open well on the farm of L. Knight, NE. sec. 1, T. 5 N., R. 8 E. (Pl. VIII, *A*). The lake beds appear to begin at the depth of 3 feet 8 inches.

Section in shallow open well of L. Knight.

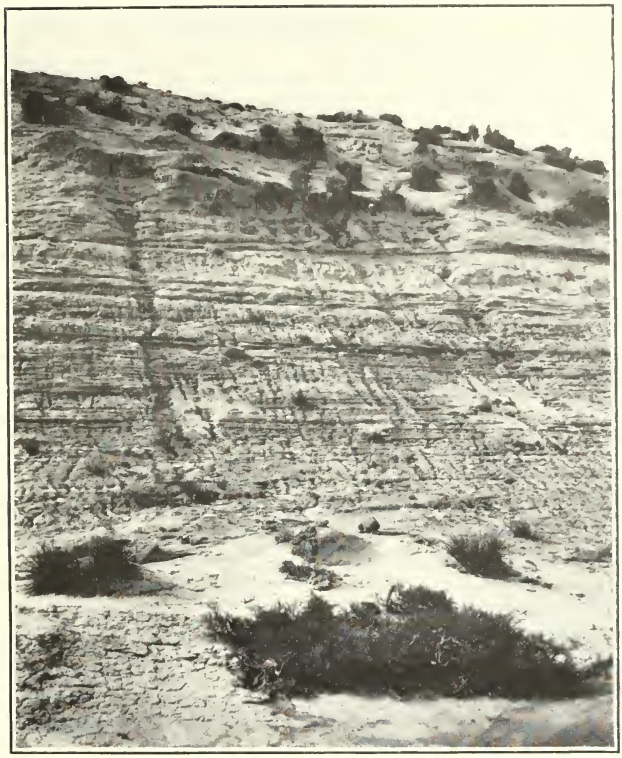
	Thickness.	Depth.
	Ft. in.	*Ft. in.*
Soil	0 6	0 6
Dark reddish gray clay	1 0	1 6
Soil belt	0 2	1 8
Dark reddish gray clay, including a few pebbles	2 0	3 8
White and yellow, fine, earthy sand, interbedded with thin strata of fine gravel	4 0	7 8
White shale, including crystals, and interbedded with thin strata of sand	4 0	11 8
Yellow, red, and gray sand, very fine	2 6	14 2

A contrast with this section is presented by a section more remote from the shore—the cliff of the salt basin in sec. 21, T. 5 N., R. 10 E. (Pls. VI, *A* and *B*, and X, *A*, and fig. 2), in which the lake sediments consist almost exclusively of laminæ of clay or shale, considerably impregnated with lime and gypsum. In some of the basins strata of fine sand were observed, but clay or shale greatly predominates in the interior area in which the salt basins are found. Borings made for soil samples also show a graduation toward finer sediments with increasing distance from the shore.

Numerous crystals, most of them of gypsum, are included in the clay or shale strata. These crystals are generally small, but in some localities large selenite crystals were found.

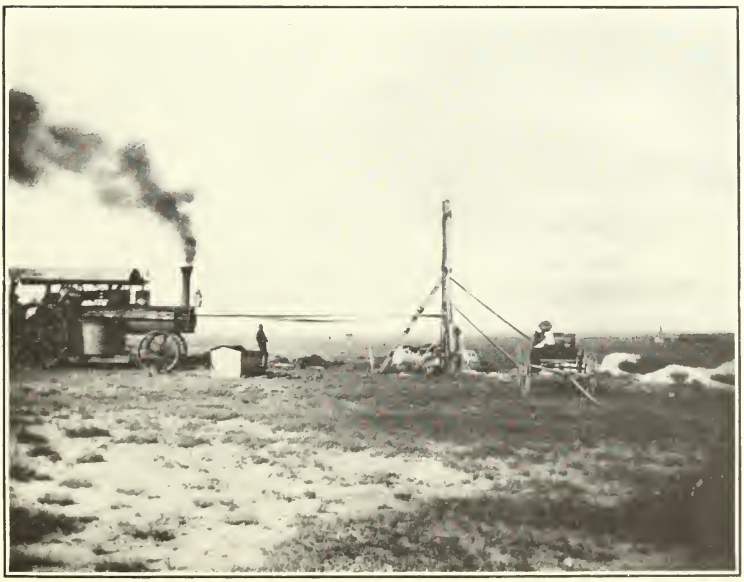
As to the thickness of the lake sediments little is definitely known, but the available evidence indicates that they are relatively thin and are underlain at no great depth by alluvial deposits. The principal evidence concerning their thickness is found in the beds of gravel (alluvial deposits) encountered in drilling on the lake flat, and in the transition in many wells from sediments of grayish hue (lake sediments) near the surface to red clay (alluvial deposits) at greater depths.

The beds penetrated by the railway well at Willard, as shown in the section given above (p. 13), appear to be alluvial rather than lake deposits. The beds below 32 feet in the deep wells of L. Knight (NE. $\frac{1}{4}$ sec. 1, T. 5 N., R. 8 E.), given in the following section as reported by the owner, also appear to be alluvial.



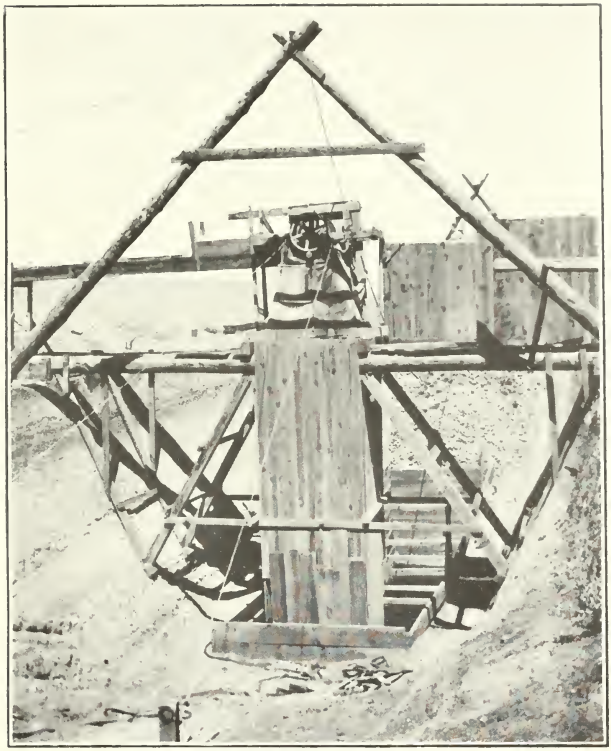
A. LAKE SEDIMENTS OVERLAIN BY WIND-DEPOSITED CLAY.

See page 23.



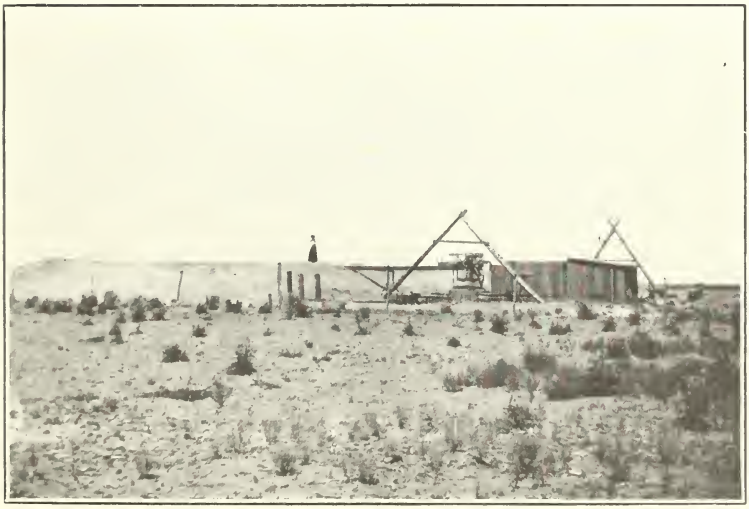
B. TESTING A WELL IN ESTANCIA.

See page 43.



A. OPEN WELL IN LAKE SEDIMENTS.

See page 24.



B. PUMPING PLANT AND RESERVOIR.

See page 54.

Section in deep wells of L. Knight.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and clay, chiefly dark-colored (in part given above)	30	30
Sticky blue mud	2	32
Gravel	8	40
White chalky material	20	60
Red clay, intermixed with white sand and gravel	30	90
Chiefly red clay with some grit	145	235
Clean gravel	5	240

WORK OF THE WIND.

SAND DUNES.

On the east side of the valley are great masses of wind-blown sand, the largest accumulations having collected east of McIntosh, in the west central part of T. 6 N., R. 11 E. and in an adjacent area to the west, and in certain localities north and south of Progresso. Much

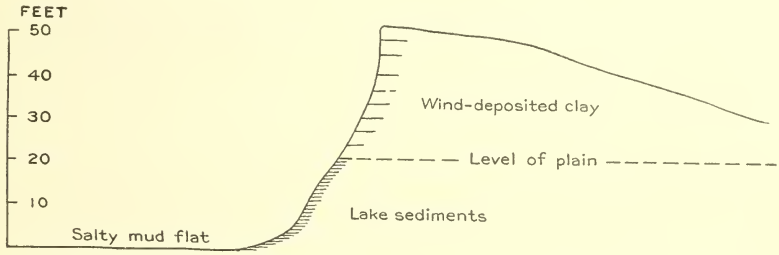


FIGURE 2.—Section of cliff surrounding salt basin.

of this sand is heaped into fresh dunes and is at present being handled by the winds. Its occurrence on the east side of the valley is due in part to a difference in the derivative rocks, but in part also to the prevailing westerly storm winds at the time the lake existed and more recently. The preponderance of sand along the east shore is characteristic of other lakes, both ancient and modern. Moreover, of the materials excavated from the salt basins the sand was generally carried farther than the clay.

SALT BASINS AND CLAY HILLS.

The salt basins in Estancia Valley are not remnants of the ancient lake—not merely low spots in which the surplus water collects until it is dissipated by evaporation—but are distinct basins sunk below the level of the plain by which they are surrounded, and as a rule are bordered by definite, nearly vertical walls. (See figs. 2 and 3.) Their flat bottoms practically coincide with the ground-water level and consist of mud covered with crusts of salt (Pl. VI, *A* and *B*), although after rains they may be submerged in water (Pl. IX, *B*). The floor of one basin

(Laguna Salina, secs. 29 and 30, T. 5 N., R. 10 E.) is covered with salt sufficiently thick and pure to be commercially valuable (Pl. IX, *A*).

Altogether there are several score of salt basins, with a total area estimated at 13,500 acres. Among these, Laguna del Perro assumes relatively gigantic proportions, for it is about 12 miles long and covers an area nearly equal to the combined area of all the other basins.

The clay hills in the valley are closely associated with the salt basins. Within the area in which they exist there are many level tracts which are essentially a part of the original plain (Pl. X, *B*). The highest clay hills project more than 100 feet above the plain on which they rest, but most of them are perhaps less than 50 feet high. Typically they form huge embankments that more or less completely encircle the salt basins (Pl. X, *A*). This form is so common that a traveler approaching a hill or ridge confidently expects to find a salt basin on the other side. In some places the ridge lies close to the basin and walls it in with a steep cliff (Pl. VI); in others it stands back a short distance, a ledge or terrace intervening between the ridge and the basin. (See Pl. IX and fig. 3.) As a rule the highest ridges are on the east sides of the basins, and the west sides of many basins are entirely open.

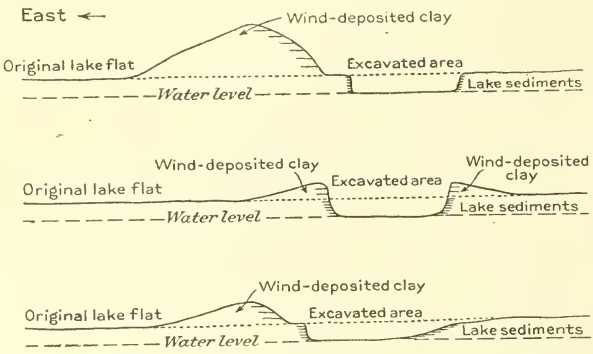


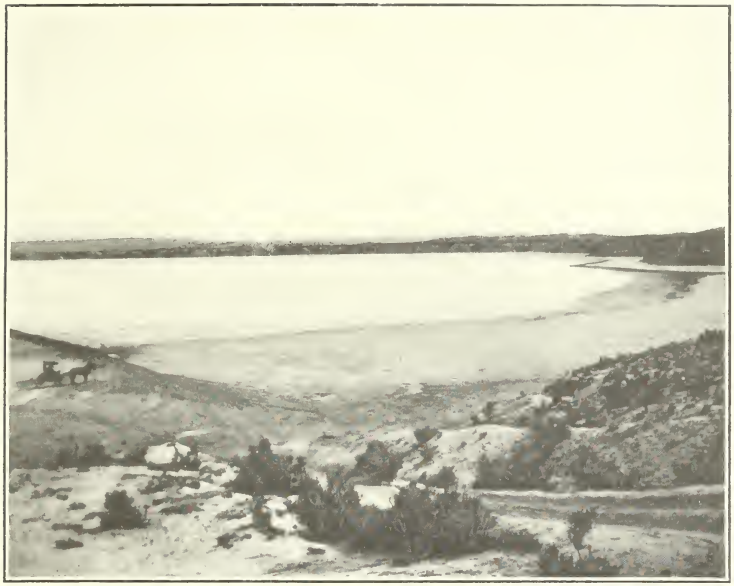
FIGURE 3.—Diagrammatic sections of salt basins and clay hills.

These hills and ridges are composed of pale yellowish gray, fine-grained, pulverulent dust or clay, and contain no pebbles or grit. The clay shows indistinct stratification and occasional cross bedding. Its structure is shown in Plate IV, *A*.

Both basins and hills are the work of wind. D. W. Johnson has described these features and has recognized the eolian character of the hills by calling them "dunes of white adobe soil."[1] Keyes refers to "shallow lake basins hollowed out of the plains-floor by the wind," and cities "Laguna del Perro and other lakelets of the Estancia plains" as typical.[2] It is difficult to conceive any other mode of origin. The material excavated from the basins was heaped up to form the hills. The work of excavation proceeded to the ground-

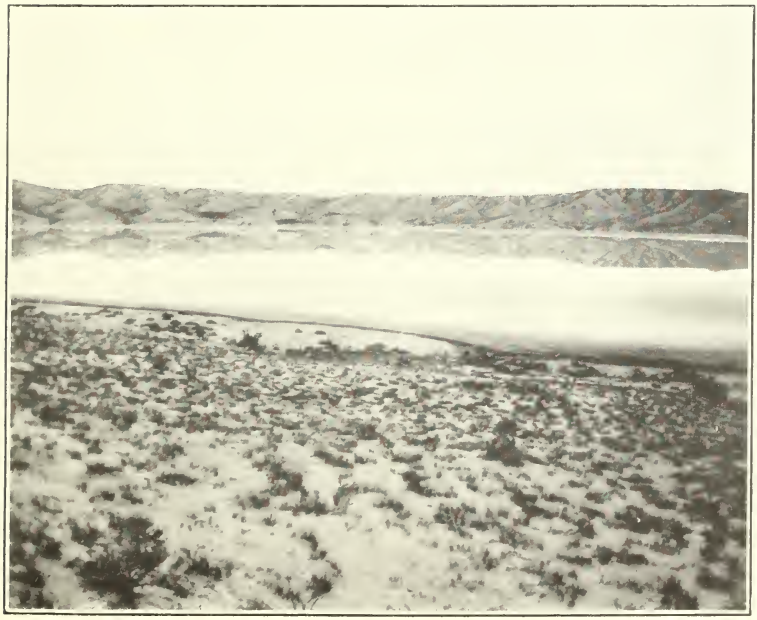
[1] Johnson, D. W., Notes of a geological reconnaissance in eastern Valencia County, New Mexico; Am. Geologist, vol. 29, 1902, p. 82.

[2] Keyes, C. R., Geologic processes and geographic products of the arid region: Bull. Geol. Soc. America, vol. 19, 1908, p. 574, and Pl. 41.



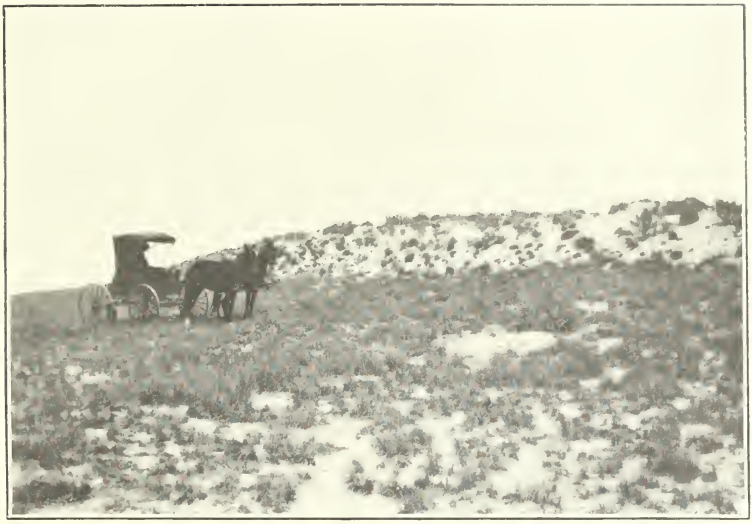
A. LAGUNA SALINA.

Showing its white incrustation of salt. See page 25.



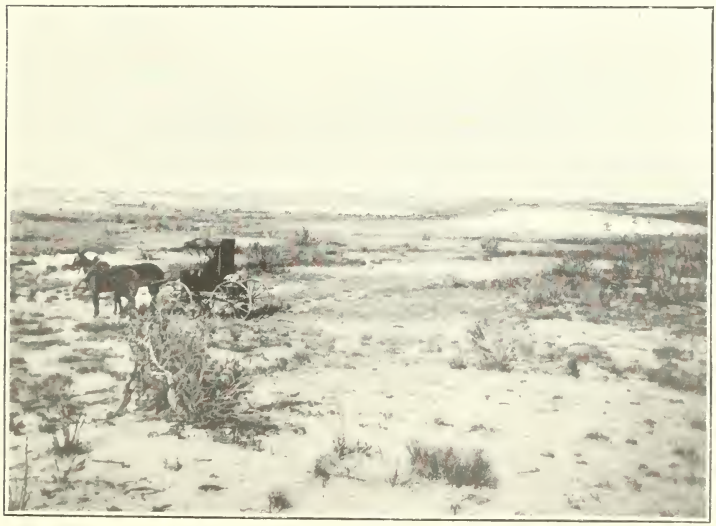
B. A SALT BASIN WHOSE FLOOR IS TEMPORARILY COVERED WITH WATER.

See page 25.



A. CLAY RIDGE BORDERING A SALT BASIN.

See page 25.



B. TYPICAL CLAY-HILL TOPOGRAPHY.

See page 25.

water level but could be carried no deeper, and hence the flat, miry, alkaline floors of the basins. The material and structure of the hills corroborates the theory of their eolian origin, the material, as far as observed, being thoroughly assorted and containing nothing coarser than the wind could handle. Southwest winds have prevailed in this region and hence the hills are best developed on the east and north sides of the basins, as is well shown in figure 4. The wind is still active and the effects of its recent erosive work can be seen on exposed parts of the basin walls.

The highest clay hills lie within the vertical range in which shore features are found and consist of material that would yield very readily to wave action, yet not the slightest indication of a shore line is recorded on their flanks, so they have evidently been formed since the lake disappeared. When the lake had dried up deflatation from the dry surface began. As the water level sank the basins were eroded deeper, and, conversely, to a certain extent the presence of the basins tended to lower the water level still more.

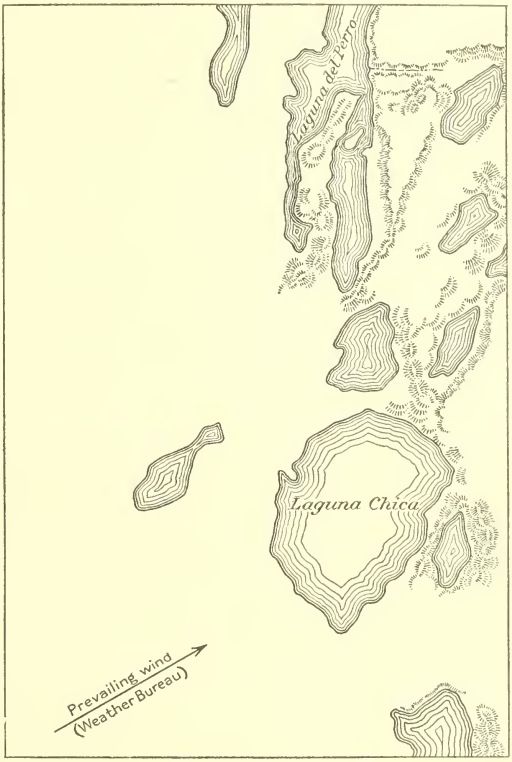


FIGURE 4.—Map showing the relation of topographic features to prevailing direction of wind. (Eastern portion of township plat, T. 4 N., R. 9 E., surveyed by Duane Wheeler.)

Attention has already been directed to the small amount of post-lacustrine stream erosion in the valley proper, in contrast to which the work of the wind is surprisingly great and impressive. Indeed, the most conspicuous and effective stream work has been done on the wind-built hills.

SOILS.

RED LOAMY SOILS.

The most widely distributed soil in the valley consists of red clay intermingled with varying quantities of silt, grit, and gravel. It is seen in typical character in the alluvial slopes and arroyos, but it also occurs throughout much of the littoral zone and is found far up in the

foothills. It is essentially the product of the weathering of the rocks in the surrounding highlands, whence it has been washed out into its present position in the manner already described. In general this soil is very fertile, as is demonstrated by the large crops that it produces when climatic conditions are not unfavorable, and its fertility is due largely to its content of soluble substances which serve as plant food. These soluble substances have been produced by the weathering of the rocks and have not been leached out from the soil by percolating waters to so great an extent as in more humid regions.

SANDY SOILS.

Sandy soils are found chiefly on the east side of the valley. They range from clean pale-yellow dune sand, which is worthless for agriculture, to red earthy sand and red sandy loam, which may be very productive. Sandy soils, like clay and loam soils, have been deprived of less of their soluble constituents in arid than in humid regions.

ALKALI SOILS.

It has just been stated that most of the soil in Estancia Valley, as in arid and semiarid regions generally, is very fertile because of the soluble substances which it contains. But if certain soluble substances, commonly known as alkalies, exist in soils in quantities too large, they are injurious to plant life; hence very fertile soils grade readily into alkali soils; and, moreover, soils which at first are very productive may, after a period of irrigation and cultivation, become harmfully alkaline. On this point Milton Whitney,[1] Chief of the Bureau of Soils, United States Department of Agriculture, makes the following statement:

> This accumulation explains the wonderful fertility of the lands generally in the arid regions the world over, but it is also a constant menace because of the large amount of soluble salts which is liable to accumulate locally as the result of irrigation or as a result of other natural conditions not well understood, until they are a menace and often a destructive agency for the very lands which were formerly held in such esteem.

The different kinds of alkali and their effects upon vegetation can best be explained by a further quotation from Whitney, as follows:

> The alkali soils of the West are of two principal classes. The alkaline carbonates or black alkali (usually sodium carbonate) is the worst form, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate (Glauber's salt), sodium chloride (common salt), magnesium sulphate, and magnesium chloride, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.
>
> The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few

[1] Alkali lands: Farmers' Bull. No. 88, U. S. Dept. Agr., 1899, p. 7.

plants can stand as much as 0.1 of 1 per cent of sodium carbonate; of sodium chloride plants can stand about 0.25 of 1 per cent, and of sodium sulphate 0.45 to 0.50 of 1 per cent. Plants can stand less salts in sandy lands than on heavy clay or gumbo lands. It is a well-known fact that crops also differ in their ability to stand salts, and many crops will grow well upon soils on which others will not live.

Investigations at Billings, Mont., showed that when the concentration of the salts in active solution in the soil moisture is as great as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural crops. It was found, furthermore, that plants could just exist with 0.45 of 1 per cent of the soluble salts present, and this is taken as the limit of plant production.

A later statement by C. W. Dorsey, of the Bureau of Soils, is as follows:[1]

Of the different classes of alkali, sodium carbonate, or black alkali, is considered the most injurious. Laboratory experiments have shown that magnesium chloride and sulphate are equally, if not more, injurious than sodium carbonate. After these salts comes sodium chloride (ordinary salt), and, last, sodium sulphate. When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate presents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.

Gypsum (calcium sulphate) acts as an antidote for black alkali by reacting with it to form calcium carbonate, which is harmless, and sodium sulphate, a less injurious white alkali. A soil that contains a large amount of gypsum would therefore not be expected to contain much black alkali, although it may contain some.[2]

In Estancia Valley the shallow water belt (Pl. XI), the ancient lake bed (Pl. I), the area of highly mineralized waters (Pl. XI), and the area in which the most alkaline soils are found, all coincide approximately with one another because all are results of the same general causal conditions. The rain water that falls on the highland borders migrates toward the lowest area, where it accumulates until it is disposed of by evaporation. Whether it here stands slightly below the general surface of the ground, as at present, or a short distance above the surface, as in the Pleistocene period when the lake existed, is merely an incident in the general circulation. The important facts in this connection are that in its migration it dissolves and carries along the soluble constituents which it encounters in the rocks and soil, and that on its evaporation these soluble constituents are left behind, thus becoming concentrated in the lowest portion of the valley. The crusts of alkali which cover the salt basins are visible illustrations of the process that has impregnated with alkali the soil of the low area.

[1] Reclamation of alkali soils: Bull. Bureau of Soils No. 34, U. S. Dept. Agr., 1906, p. 10.

[2] Cameron, F. K., Application of the theory of solution to the study of soils: Field operations, Div. of Soils, 1899, U. S. Dept. Agr., 1900, pp. 152 et seq. Hilgard, E. W., Soils, Macmillan Co., New York, 1906, pp. 449 et seq., 457, 458.

Samples of soil collected at five points within the lake flat along a line extending 6 miles eastward from Estancia (see the map, Pl. XI) were analyzed by the United States Bureau of Soils, with the following results:

Analyses of soils in Estancia Valley.

Location.	Depth within which the material was obtained.	Soluble solids (alkalies); per cent of total material.	Predominating salts in the order named.
	Feet.		
Estancia, NW. ¼ sec. 12, T. 6 N., R. 8 E., at the intersection of the railway with the section line.	1	0.2	Chlorides and bicarbonates.
	2	.3	Do.
	3	.8	Sulphates and chlorides.
	4	1.0	Do.
	5	1.2	Do.
	6	1.0	Do.
T. J. Moore, northeast corner of SW. ¼ sec. 5, T. 6 N., R. 9 E.	1	.1	Do.
	2	1.4	Chlorides and sulphates.
	3	1.3	Sulphates and bicarbonates.
	4	1.5	Do.
	5	2.1	Sulphates and chlorides.
	6	1.6	Do.
Southwest corner of sec. 4, T. 6 N., R. 9 E.....	1	.6	Do.
	2	.7	Chlorides and sulphates.
	3	3.7	Sulphates and chlorides.
	4	3.9	Do.
	5	3.7	Do.
	6	3.5	Do.
N. Williams, southwest corner of SE. ¼ sec. 3, T. 6 N., R. 9 E.	1	2.5	Do.
	2	2.7	Do.
	3	2.9	Do.
	4	2.7	Do.
	5	2.9	Do.
	6	3.5	Do.
H. N. Summers, southeast corner of SW. ¼ sec. 1, T. 6 N., R. 9 E.	1	1.6	Do.
	2	2.8	Do.
	3	3.7	Do.
	4	4.5	Do.
	5	3.6	Do.
	6	4.5	Do.

In respect to these analyses J. A. Bonsteel, in charge of soil surveys, writes:

It is apparent to the student of soils and soil conditions in the Basin region that these soils are very heavily loaded with alkali salts, comparing more directly with those of old desiccated lake basins than with any of the agricultural lands now occupied in the United States. You will also notice the continual appearance of chlorides in practically all of the samples. From this I judge that the soil samples were taken from a decidedly alkaline tract, probably a desiccated lake bed, and where only the most efficient tile underdrainage would render the majority of these soils capable of producing any economic vegetation.

CLIMATE.

RAINFALL.

The following tables give the monthly and annual precipitation in Estancia Valley as recorded by the United States Weather Bureau. They cover a period that is too short to serve as a reliable basis for estimating the average monthly and yearly precipitation, but they are, nevertheless, exceedingly instructive.

Precipitation in Estancia Valley, in inches, 1903–1909.

Estancia.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1904	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.10	0.75	.....
1905	1.00	0.94	0.38	2.68	0.01	1.13	.....	1.07	1.16	.....	.....	.....	.....
1906	.08	.33	.69	1.37	.03	.00	4.41	1.73	1.49	2.17	1.33	1.13	14.76
1907	.40	.21	.00	1.97	1.22	.90	.56	4.71	.....	1.94	2.11	.....	.....
1908	.20	Tr.	.....	.....	.....	.....	4.46	.....	.....	.....	.....	.....	.....
1909	.....	.....	.....	.....	.....	1.00	.99	1.30	1.25	1.36	.10	.78	.....

Mountainair.

1903	0.60	5.39	0.46	0.43	0.06	2.96	0.52	1.71	0.36	Tr.	0.00	0.52	13.01
1904	.10	Tr.	.14	.14	.57	2.38	1.11	2.45	2.66	0.98	.03	.34	10.90
1905	.72	1.64	1.09	3.66	.32	1.11	2.47	1.60	3.12	.31	3.74	3.04	22.82
1906	.40	1.11	.28	.....	.....	.....	.....	.....	1.43	1.96	1.49	2.84	.....
1907	1.38	.31	.06	2.68	4.24	.12	1.19	4.88	1.99	3.45	2.22	.34	22.86
1908	.60	.51	.36	3.00	.61	.66	4.78	2.50	.78	.77	1.73	.37	16.57
1909	.18	.80	4.92	.22	.18	.06	2.31	2.53	1.90	1.61	Tr.	1.79	16.50
Average	.57	1.40	1.04	1.69	1.00	1.21	2.06	2.61	1.75	1.30	1.32	1.32	17.11

Otto.

1909	0.45	0.25	0.40	0.36	0.29	0.37	1.27	2.00	2.47	0.54	0.20	0.25	8.85

Estancia Valley clearly belongs to the semiarid belt, its rainfall being deficient in quantity and irregular in distribution. Much more rain falls in some years than in others, much more falls in some months than in others of the same season, and much more falls during a certain month in one year than during the same month in other years. A large share of the rain comes in heavy downpours of short duration, covering limited areas and occurring at irregular and often at long intervals. The heaviest precipitation is in July and August. There is frequently a deficiency in the winter and spring months.

During the summer the great cyclonic storms which regularly pass eastward across the continent have relatively little effect in this region, but the showers are generally produced by ascensional currents resulting from the daily heating of the atmosphere. Nearly every afternoon the temperature rises, the barometric pressure decreases, and the weather becomes threatening. Most of the storms blow over with a few stray raindrops, but occasionally one bursts with fury and the rain descends in torrents.[1]

The above tables cover too brief a period and are too incomplete to afford a basis for definite conclusions, but they indicate more rainfall at Mountainair than at Estancia. Of the 37 months in which records are available for both stations 27 months show greater rainfall in Mountainair and only 10 months show greater rainfall in

[1] Henry, A. J., Climatology of the United States: Bull. U. S. Weather Bureau Q, 1906, pp. 50, 888–889.

Estancia. Moreover, in these 37 months 58.53 inches fell in Mountainair and only 41.90 inches fell in Estancia. This difference is graphically shown in figure 5.

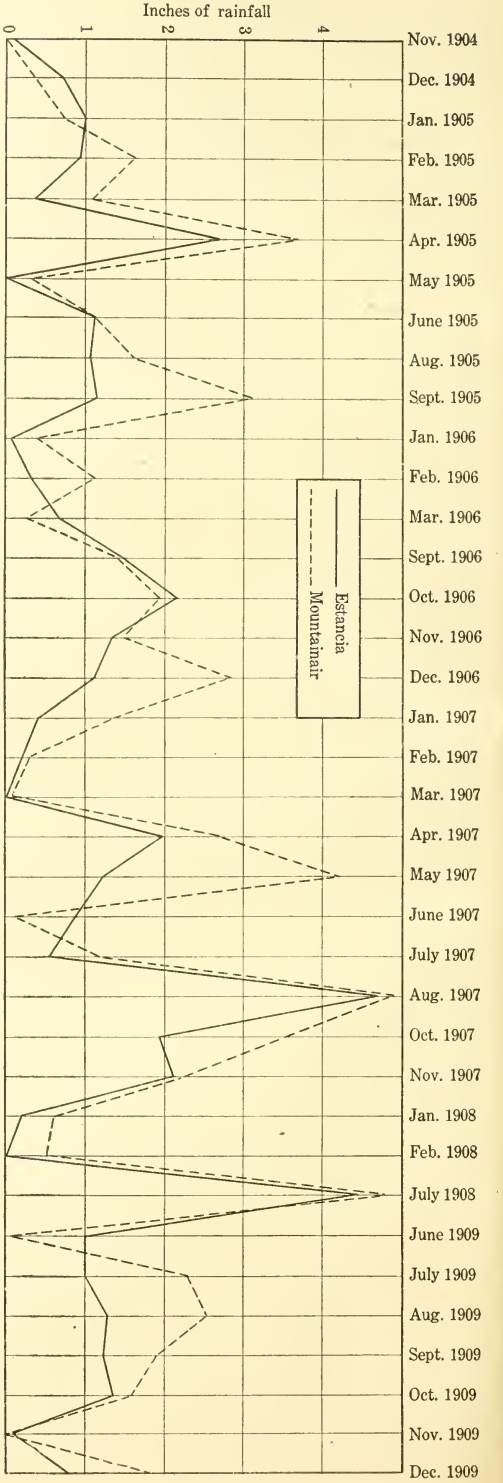


FIGURE 5.—Diagram showing relative amounts of rainfall at Estancia and Mountainair during months in which observations were made at both places.

EVAPORATION.

The term "annual evaporation" is used to mean the total thickness of the layer of water that would be removed by evaporation from the surface of a lake or other body of water continuously exposed to the atmosphere for one year. It is as important a factor of climate as is rainfall. It varies inversely with the relative humidity of the atmosphere and directly with temperature and wind velocity. At Albuquerque the average evaporation for two years (1900 and 1903) was 82.9 inches;[1] at Amarillo, Tex., it was reported to be 55.4 inches.[2] In Estancia Valley it is probably less than at Albuquerque and more than at Amarillo.

TEMPERATURE.

The following table gives the meager data at present available as to the mean

[1] Lee, W. T., Water resources of the Rio Grande Valley in New Mexico: Water-Supply Paper U. S. Geol. Survey No. 188, 1907, p. 31.

[2] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 677.

annual temperature, the highest and lowest temperatures, and the dates of latest frosts in the spring and earliest frosts in the fall:

Temperatures in Estancia Valley, 1903–1909, in degrees Fahrenheit.

Years.	Mean annual.		Highest.		Lowest.		Last killing frost in spring.		First killing frost in fall.	
	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.	Estancia.	Mountainair.
1903	.....	49.4	.....	95	.....	−12	.....	May 25[a]	.....	Sept. 17
1904	.....	50.3	.....	74	.....	− 3	.....	May 9[a]	.....	Sept 8[a]
1905	.....	[b]49.1	94	96	− 6	−13	Apr. 23[a]	May 12[a]	Sept 15	Sept 30
1906	50.2	.....	95	92	16	− 2	May 8	.....	Oct. 6	Oct. 11
1907	.....	[c]52.4	95	95	7	− 2	June 12[a]	May 29[a]	Sept. 25[a]	Oct. 9[a]
1908	.....	51.0	94	95	7	7	.....	May 13	.....	Sept 27
1909	.....	.....	.....	.....	.....	.....	.....	May 15[a]	.....	.....

[a] Minimum temperature of 32° or lower.
[b] Interpolated.
[c] Obtained by averaging the monthly means.

The following statement by A. J. Henry,[1] of the United States Weather Bureau, in regard to New Mexico in general, applies for this region:

The daily variation of temperature is very great. * * * Owing to the dryness of the air, the extremes of temperature are not such potent factors in the comfort of animal life as the degrees registered by the thermometer would indicate. It is a noteworthy fact that 100° in the shade here is not so oppressive as a temperature of 85° in a humid climate. Sunstrokes are unknown in New Mexico. In a somewhat corresponding degree the cold of winter is felt less. Spring advances slowly, development being retarded by the cold nights as well as by the lack of moisture. * * * May, June, July, and August are characterized by extremes of heat during the middle of the day, but the nights are cool.

WIND.

Late winter and early spring are characterized by high winds which make outdoor life unpleasant, but destructive winds are rare. Later in the year there is less wind and the climate is generally very agreeable.

The following table, which gives data as to the prevailing direction of the wind, is introduced especially because of its bearing on the wind theory of the formation of the clay hills and the location of the sand dunes:

Prevailing direction of wind in Estancia Valley.

Summarized by years, 1903–1909.

	1903	1904	1905	1906	1907	1908	1909
Estancia	.....	.....	SW.	W.	.....	.....	.....
Mountainair	SW.	SW.	SW.	SW.	SW.	SW.	SW.

Summarized by months for 1907.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Estancia	.....	.....	W.	.....	.....	SW.	SW.	.....	.....	.....	NW.	.....
Mountainair	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW.	SW	SW.

[1] Henry, A. J., Climatology of the United States: Bull. U. S. Weather Bureau, Q., 1906, p. 888

The next table gives the average wind velocity for one year at four points in the general region to which Estancia Valley belongs. It is presented because of its bearing on the data given on page 59 in regard to the pumping capacity of windmills.

Average wind velocity in the Southwest in 1907, in miles per hour.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
El Paso, Tex.	8.1	10.4	10.4	13.2	12.5	11.0	9.8	8.0	7.0	8.8	7.9	9.4
Mesilla Park	5.8	6.9	8.5	10.7	10.4	8.1	8.4	7.5	6.1	.....	5.5	6.6
Roswell	6.1	6.7	7.7	7.6	7.2	6.0	5.2	4.5	5.0	4.6	4.6	7.1
Santa Fe	7.2	8.2	8.6	8.0	7.8	7.2	6.7	7.3	7.3	7.6	7.7	9.5

RELATION OF CLIMATE TO AGRICULTURE.

The mean annual rainfall, taken by itself, gives very incomplete information as to the adaptability of the region to agriculture, for the distribution of the rainfall, the rate of evaporation, and other factors are vital elements of the problem. The preponderance of precipitation in the summer over the winter season is obviously favorable to agriculture, but the deficiency of rainfall in the spring, its general irregularity, and the fact that much of it comes in short heavy showers are unfavorable, as are also the low humidity of the atmosphere and the strong spring winds, both of which intensify evaporation.

WATER.

SOURCE AND DISPOSAL.

If the mean annual precipitation for the entire Estancia Basin is assumed to be 15 inches, the amount of water that falls on the basin as rain or snow in an average year is approximately 1,600,000 acre-feet. If it is further assumed that within recent years the quantity of ground water has neither materially increased nor decreased, it follows that the same amount is, on the average, withdrawn each year from the Estancia Basin. This withdrawal is accomplished by evaporation into the atmosphere and by seepage through underground passages to lower points outside of the basin. No water leaves the basin in surface streams.

EVAPORATION FROM THE SURFACE.

Much of the water that falls as rain or snow returns to the atmosphere by being evaporated, either directly from the surface or after it has soaked a short distance into the ground, from which it is again withdrawn by vegetation or by capillary action in the soil. The proportion of moisture thus disposed of is greatest for the lightest showers and least for the heaviest and most persistent rains.

MOUNTAIN SPRINGS AND STREAMS.

Some of the moisture that falls on the mountains seeps into the pores and crevices of the rocks, but reappears at lower levels, where it issues in springs that give rise to brooks or rivulets, most of which disappear long before they reach the valley, the water being dissipated both by evaporation and by seepage into the ground. Springs and streams of this type in the canyons and foothills of the Manzano Range have determined the location of the old Mexican settlements of Chilili, Tajique, Torreon, Manzano, and Punta de Agua.

FLOODS.

In the entire basin there are no permanent streams except the tiny ones just mentioned, but there are many wide stream channels, or arroyos, which are normally dry, but which during heavy storms carry much water. The water of most of these floods is lost in the arroyos, but that of a few of the largest reaches the central flat and there soaks into the earth. Probably these floods furnish most of the ground water in the valley fill.

UNDERFLOW.

Though the valley includes no important permanent surface stream it contains a great body of ground water which, below a certain depth, fills every pore, crack, and crevice. From time to time this great body of water receives contributions from portions of the rainfall that escape evaporation. It is not, however, a stationary mass, for it moves constantly, though very slowly, away from the upland border and toward the low central portion of the basin.

OVERFILLING OF UNDERGROUND RESERVOIR.

If the ground water is constantly augmented by contributions from the rainfall, and if this newly acquired water moves constantly toward the center of the valley, it would be expected that in the central region the pores and crevices of the ground above the bed rock would in time all become filled and the underground reservoir would overflow. This is essentially what takes place, the surplus being returned to the surface or brought so near to the surface that it can be reached by evaporation. The surplus is disposed of in three ways—by overflow from valley springs, by evaporation from the salt basins, and by evaporation in other areas in which the ground water rises near enough to the surface to come within the reach of the atmosphere through capillarity. In each of the three ways the ultimate disposal of the water is by return to the atmosphere through the process of evaporation.

There are several valley springs, two of the largest and best known of which are Estancia Spring, in the village of Estancia, and Antelope Spring, several miles north (Pl. I)—both important watering places in the old days before the advent of the agriculturist. From general observations it seems safe to say that their combined yield does not exceed several hundred acre-feet per year—an amount which is insignificant when compared with the total quantity of water that falls upon the Estancia Basin each year as rain or snow.

Where the ground water lies sufficiently near the surface, it is withdrawn in the same manner and by the same process that kerosene is withdrawn through the wick of a burning lamp, the soil serving as the wick. The moisture at the top of the soil is constantly being removed by evaporation just as the kerosene at the top of the wick is removed by burning, and new moisture is drawn up through the pores of the soil just as kerosene is drawn up through the pores of the wick. In both cases the liquid is lifted by capillarity.

There is a limit to the height that water can be lifted by capillarity, but this limit is not the same for different soils. It can be lifted higher through clay or fine silt, which has small pores, than through sand, which has larger pores. Hilgard states that the maximum height of capillary rise thus far observed is 10.17 feet.[1] C. H. Lee concludes that in the area he has investigated in Owens Valley, Cal., no appreciable evaporation occurs from soil where the depth to water exceeds 8 or 9 feet.[2] For most soils, capillarity is probably not effective except where the water stands considerably nearer the surface than 10 feet.

The rate at which water is raised by capillary action depends on the character of the soil and the height that the water is lifted. It is more rapid in sandy soil than in clay soil, and more rapid where the water is near the surface than where it is several feet below the surface. In an experiment made at Deerfield, Kans., in 1905, Slichter[3] found that the evaporation during the period from August 6 to September 3 was as follows: From open water, 10.90 inches; from cultivated soil with 1 foot to water, 4.88 inches; from uncultivated soil with 1 foot to water, 5.83 inches; from soil with 2 feet to water, 2.23 inches; from soil with 3 feet to water, 0.80 inch. The soil was sandy loam. Lee [2] concluded from his experiments in Owens Valley that where the water level is not more than 3 feet nor less than 1 foot below the surface, a depth of evaporation of about 80 per cent of that from an exposed water surface can be expected.

The salt basins of Estancia Valley are a part of the time miry or covered with water, and are probably in general near enough the water

[1] Hilgard, E. W., Soils: MacMillan Co., N. Y., 1906, p. 203.

[2] Precipitation, run-off, and evaporation in the Owens Valley: Monthly Weather Review Weather Bureau, U. S. Dept. Agr., vol. 38, No. 1, Jan., 1910, p. 127.

[3] Slichter, C. S., The underflow in Arkansas Valley in western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, p. 44.

level to permit evaporation from the ground water. If their total area is taken as 13,500 acres and the annual evaporation from open water is taken as 72 inches, then the amount of water that would be removed from their surface each year if they were continually covered with water is 81,000 acre-feet, or about 5 per cent of the total precipitation in the Estancia Basin. Where the water level is very near the surface evaporation may take place even more rapidly than from open water, but since in certain places and certain seasons it is probably some distance below the surface the actual average rate of evaporation is probably much less than for open water. Moreover, much of the evaporating potentiality is consumed in removing surface water which runs in from the clay hills during heavy showers.

Evaporation of ground water is also taking place in some localities outside of salt basins, and it seems probable that the amount of water withdrawn in these localities is quantitatively important. Near the McGillivray well, in Estancia, where the water is only 5 feet below the surface, incrustations of salt were observed, although similar incrustations were not evident in the soil of the same locality where the depth to ground water is greater, this being true of the red soil that lies at a higher level to the west and also, to a certain extent, of the "ashy" soil that lies at a lower level to the east. Similar conditions were observed elsewhere along the shallow-water belt on the west side of the valley. East of Moriarty there are also areas of very shallow water in which crusts of salt have formed at the surface such as are not generally found in the central part of the valley. The explanation seems to be that where the ground water lies at a shallow level it is drawn to the surface and evaporated, leaving its content of salt. The total area outside of the salt basins having a depth to water of less than 10 feet is perhaps as great as the area of the salt basins themselves.

LEAKAGE OF THE BASIN.

As has been repeatedly indicated, the rock formations which border the valley and underlie the valley fill constitute a relatively impervious basin in which the water collects. But this basin is perched high above most of the surrounding territory and if it is not entirely waterproof serious loss may occur. The extensive outcrop of more or less porous rock formations east of the Manzano Range produces a condition favorable for the absorption by these formations of water that falls upon the outcrop or crosses it in coming from the mountains. To the extent that this absorbed water finds passages of escape through porous strata or fissures formed by deformation or in other ways, to that extent the water of the basin is lost. It is possible that such escape occurs through the nearly horizontal strata to the south, through the north end, or through the fissures and porous strata to

the east. The conditions here involved are so complex and obscure that it is impossible to form an estimate of the amount of this leakage, but it may be a large factor.

SUMMARY.

The foregoing analysis of the disposal of the water that falls on the Estancia drainage basin is summarized in the following table. The analysis is not exhaustive, but is sufficiently complete for practical purposes.

Disposal of precipitation in the Estancia Basin.

Process.			Quantitative importance.
Evaporation.	Before reaching the ground water.	Before soaking into the ground.	Great, but indefinitely known.
		After soaking into the ground. Withdrawn by vegetation, capillarity of the soil, etc.	
	After seeping into the rocks, from which it is returned through mountain springs.		Small.
	After reaching the ground water in the valley fill.	Returned through valley springs.	Small.
		Returned by rising in salt basins.	Appreciable.
		Returned by approaching near the surface in other localities.	Probably appreciable, but indefinitely known.
Seepage.	Entering into the pores and crevices of the rocks and escaping from the basin.		Indefinitely known. Possibly great.

HEAD.

GROUND-WATER TABLE.

METHODS OF INVESTIGATION.

Below a certain level the earth is saturated, every pore and crevice being filled with water. This level is known as the ground-water level or ground-water table. To ascertain its position relative to the surface throughout the valley the depth to water was measured in about 200 wells and was reported by owners, drillers, or other reliable persons for many more. The measurements were made with a stout cord, which was marked at intervals of 3 feet. This allowed much more rapid work than the use of a steel tape, and the error due to the elasticity of the cord was less than 1 per cent. A more serious error, or rather ambiguity, arose from the fact that the ground is

MAP OF ESTANCIA VALLEY, NEW MEXICO, SHOWING DEPTH TO AND QUALITY OF THE GROUND WATERS

LEGEND

Salt basins. Water near surface

Depth to water less than 25 feet

Depth to water between 25 and 50 feet

Depth to water between 50 and 100 feet

Depth to water over 100 feet

Parts per million of sulphate radicle determined by the turbidimeter method

Contents of chlorine in parts per million

Contents of sulphate radicle in parts per million

Less than 30

Between 100 and 625

More than 625

Point where samples of soil were taken, and percentage of alkali in the upper 6 feet

generally graded up around a well, making it uncertain as to what level should be taken as the natural land surface, to which all measurements were referred. The element of error is of no practical importance in the determination of the general position of the ground-water table, but it must be taken into account if future measurements are made for the purpose of detecting changes in the water level. The general results are shown on the map, forming Plate XI, and more specific data are given in the table on page 67.

RELATION OF GROUND-WATER TABLE TO THE SURFACE.

Over an area of about 240 square miles (including the salt basins) the ground water stands within 25 feet of the surface, over an area of about 210 square miles it stands between 25 and 50 feet below the surface, and over an area of about 250 square miles it stands between 50 and 100 feet below the surface. Thus, over a total area of about 450 square miles it is less than 50 feet below the surface, and over a total area of at least 700 square miles it is less than 100 feet below the surface. The shallow-water area covers the low central plain and extends far up the large arroyos, especially Arroyo Mesteño. The map, Plate XI, indicates the general boundaries of the areas of different depths to water as nearly as these could be ascertained, but numerous small areas in the foothills in which water is locally found at depths of less than 100 feet are not shown.

SHALLOW-WATER BELT ON THE WEST SIDE.

About a mile west of the New Mexico Central Railroad and extending nearly due north and south for a number of miles is a narrow belt in which the ground water is very near the surface. This belt runs along the base of the cliff on the McIntosh ranch (SE. ¼ sec. 35, T. 8 N., R. 8 E.), whence it extends northward to the east side of sec. 23 and perhaps beyond. It passes southward through Antelope Spring; thence through secs. 23, 26, and 35 in T. 7 N., R. 8 E., to secs. 2 and 11 in T. 6 N., R. 8 E., and to Estancia Spring; thence to secs. 26 and 35 in the same township and through secs. 2, 3, 10, 11, and 15 in the next township south, beyond which it was not traced. Along this line, wherever data were obtainable, the ground water was found near the surface, at depths in most places of less than 10 feet and in some places of less than 5 feet. It can not be asserted, however, from the data available, that there are no interruptions in this shallow-water belt.

It is not closely related to the topography, for the surface rises toward the west and gradually descends toward the east, yet in both directions the depth to water increases. Thus, on the McIntosh ranch the water is virtually at the surface, but less than half a mile east and at a level about 25 feet lower it is 30 feet below the surface;

at Antelope Spring it is at the surface, but 1 mile east and at a considerably lower level it is 35 feet below the surface; on sec. 2, T. 6 N., R. 8 E., it is only 8 feet below the surface, but a short distance east and at a lower level it is 20 feet below; in the west part of Estancia it is practically at the surface, but in the east part, which is lower, it is 15 or 20 feet below; at a point 1½ miles west of the railway, along the line between townships 5 and 6, it is only 4 feet below the surface, but at a considerably lower point half a mile east of the railway it is 22 feet below; in the SW. ¼ sec. 14, T. 5 N., R. 8 E., it is only 14 feet below the surface, but 1 mile farther east and on ground perhaps 15 or 20 feet lower it is 32 feet below. In some localities it would be possible, though perhaps not practicable, to draw the ground water from the shallow belt by gravity through a tunnel or siphon out to the surface farther east. Indeed, such a scheme is being attempted by H. C. Williams on sec. 26, T. 6 N., R. 8 E.

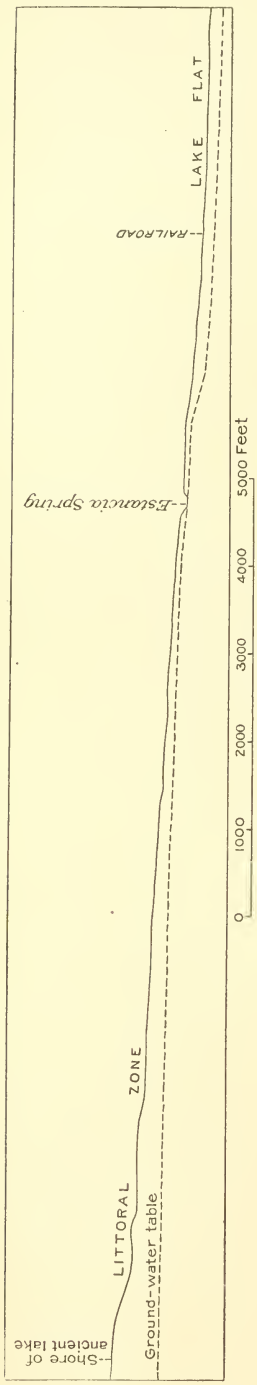


FIGURE 6.—Section through Estancia village showing the relation of the shallow water belt to the surface.

This shallow-water belt is shown on the map, Plate XI, and in figure 6 it is shown in a cross section passing through the village of Estancia, the only locality in which wells have been sunk close enough to each other to make such a section possible. The cause of this abrupt change in the ground-water level is not evident. At Antelope Spring and McIntosh ranch it might be correlated with the cliff immediately west, but such an explanation will not hold farther south. Neither underground structure, concentric arrangement of beach materials, nor the existence of the salt basins appear to furnish an adequate explanation.

INFLUENCE OF THE SALT BASINS.

Although the ground-water table is nowhere at any great depth throughout the low central portion of the valley, it does not approximate as closely

to the surface as it would if the salt basins were absent. Moreover, these depressions are perhaps chiefly responsible for the scarcity of springs and seeps in this region.

RELATION OF GROUND-WATER TABLE TO UNDERFLOW.

The ground-water table is not level, but slopes toward the center of the valley, although, in general, this slope is less steep than that of the land surface. An approximate idea of the amount of slope, or the "hydraulic gradient," can be deduced from the map, Plate XI, but it will be only approximate, because the topographic contours are based largely on aneroid readings and are therefore only approximately correct. In the following table somewhat more accurate data are given for several stations whose altitudes were determined by railway levels:

Slope of ground-water table in Estancia Valley.

Station.	Altitude of surface above sea level.	Depth to water.	Altitude of ground-water table above sea level.[a]	Difference in altitude of ground-water table.	Distance from preceding station.	Hydraulic gradient, or slope of ground-water table.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Miles.*	*Ft. per mile.*
Stanley	[b] 6,317	[c] 115	6,202			
Moriarty	[b] 6,204	40	6,164	38(?)	11.5	3.3(?)
McIntosh	[b] 6,136	30	6,106	58	8.5	6.8
Estancia	[b] 6,093	15	6,078	28	7	4.0
Willard	6,090	35	6,055	23	12	1.9
3 miles east of Willard	[d] 6,055	10	6,045	10	3	3.3
Progresso	[b] 6,167	35	6,132	87	8	10.9
Cedarvale	[d] 6,425	174	6,251	119	15	8.0
Mountainair	6,487	[c] 210	6,277			
Broncho	6,312	175	6,137	140	6	23.3
Willard	6,090	35	6,055	82	7	11.7
3 miles east of Willard	[d] 6,055	10	6,045	10	3	3.3
Pato	6,085	25	6,060	15	3	5.0
Lucia	6,187	[c] 40	6,147	87	7.5	11.6
Venus	[f] 6,555	180(?)	6,375(?)			
Moriarty	[b] 6,204	40	6,164	211(?)	10.5	21.0(?)

[a] In the deep wells the artesian head is given.
[b] Gannett's Dictionary of Altitudes.
[c] Approximate. Data somewhat conflicting.
[d] Estimated.
[e] Reported by A. T. & S. F. Ry. Co.
[f] Elevation relative to Moriarty, according to railway survey.

It has already been explained that the ground water is not stationary, but is constantly, though very slowly, moving toward the low central part of the valley. If no new supplies were received at the borders and none were removed in the center of the valley the ground water would in time find its level and come to rest. Other things being equal, the steeper the slope the more rapid is the motion of the ground water. On this basis a generous supply and vigorous underflow are indicated from the western and northwestern mountains, but a meager supply and sluggish underflow from the north end.

RELATION OF GROUND-WATER TABLE TO SUPPLY AND DISPOSAL.

It has been seen that there is an equilibrium between the supply of water from the rainfall that is annually added to the underground store and the amount annually removed from this store by evaporation and seepage. Fluctuations in the ground-water level, whereby the amount of evaporation is regulated, tend to maintain this balance through changing climatic conditions. If the rainfall should decrease and thereby diminish the annual increment to the underground store, then, by the excess of loss over gain, the ground-water level would be lowered. This in turn would decrease the flow of the springs and the evaporation from the salt basins and other shallow-water areas. Ultimately a level would be reached at which the loss would no longer be greater than the gain. A similar adjustment would take place if the rainfall remained the same while the evaporating power of the atmosphere increased. If, on the other hand, the amount of rainfall should increase or the evaporating power decrease, or, as is more probable, if both these changes should take place at the same time, then the ground-water level would rise, new springs would burst forth, the salt basins would fill and even perhaps overflow, and capillary action would become effective over a larger area, until at last loss and gain would again balance.

There are constant fluctuations in the water level as rainy and dry seasons alternate and rainy and dry years or periods of years succeed each other. In some wells fluctutations of several feet within the past few years were reported. Thus the boundaries of the areas having specified depths to water, shown in Plate XI, are not stationary, but expand after humid periods and again contract after periods of drought. In Pleistocene times, when throughout the continent the climate became notably humid, the water level in Estancia Valley rose greatly and equilibrium between increment and disposal was not established until a large lake had accumulated, exposing hundreds of square miles of water surface to continuous and unrestricted evaporation.

ARTESIAN CONDITIONS.

IN THE VALLEY FILL.

If a well is drilled to some depth below the point where water is first encountered and this shallow water is cased out, the water from greater depths generally rises in the well at least to the level of the shallow water and in many places a few feet higher, but no well was found in Estancia Valley in which the artesian pressure from the deeper horizons of the valley fill is sufficient to lift the water above the surface of the ground, although in the shallow-water belt on the west side of the valley it is possible to secure flows by drifting or tunneling. In closed basins of the type to which Estancia Valley

belongs flows are frequently obtained from wells drilled in the valley fill of the low central areas. The relatively unfavorable condition in Estancia Valley in regard to flows, as also in regard to springs and seeps, suggests that there is a relative dearth of ground water. It is, however, doubtful whether such an inference is justified, since the salt basins introduce an unusual feature which may be wholly responsible for the unfavorable conditions. Moreover, the slope of the sides is not as steep as in many basins that have flowing wells.

IN THE ROCK FORMATIONS.

The sedimentary rocks on the west side of the valley dip eastward from the mountains toward the valley, and to some extent the rocks on the east side also dip toward the valley. Moreover, in some of the rock wells on the west slope the water rises under considerable pressure. In the railway wells at Mountainair, for example, water from a depth of 295 feet is reported to rise 85 feet, which brings it to about 6,277 feet above sea level and about 200 feet above the center of the valley. These conditions gave rise to a hope that artesian wells could be obtained in the valley by drilling into the rock formations.

Accordingly several test wells have been sunk. The deepest one, located 4 miles east of Estancia (SW. ¼ sec. 10, T. 6 N., R. 9 E.), in the heart of the valley, passes through more than 400 feet of red shale and sandstone, as has already been stated, and ends in "hard gray rock" at a depth of nearly 800 feet. The results have not been favorable. At several horizons the water rose slightly above the surface, but no flow of any practical consequence was obtained.

RECOVERY OF WATER.

In the foregoing pages it has been shown that the ground water constantly receives new supplies on the high land and that it migrates slowly but constantly toward the valley, where the excess is disposed of by evaporation. On its way a small amount is at present intercepted and pumped to the surface. The extent to which the water can be recovered by human agencies for human use is a matter of great practical importance. Two phases of this question will here be considered, the yield of wells and the total amount of water available.

YIELD OF WELLS IN THE VALLEY FILL.

A large amount of miscellaneous information in regard to the yield of wells was collected, but unfortunately the bulk of this information is of little value because few wells have been sunk deep enough to reach the strongest water horizons and most of the pumping tests have not exceeded a few gallons per minute. A few rather conclusive tests were reported, however, and through the generous assistance of R. B. Cochran, of Estancia, several others were made in the course of this investigation.

Throughout most of the valley there is no difficulty in procuring ample supplies for domestic purposes and for the use of stock, but there are a few localities where even this amount of water is hard to obtain. Near the north end of the valley no wells were seen, and, owing to the northern exposure of the deposits that here underlie the valley, the prospects of procuring water except at considerable depths are not encouraging. In general the yield of wells appears to be better on the west side than on the east side of the valley.

At Willard the Atchison, Topeka & Santa Fe Railway Co. drilled a number of wells. The deepest one entered red sandstone at 312 feet and was continued in this rock to 440 feet, at which depth the drilling was stopped. Within the first 312 feet numerous beds of coarse gravel supplied water freely. Fourteen 8-inch wells were sunk at intervals of about 120 feet to depths of approximately 200 feet. An air lift was applied to 12 of these wells simultaneously for 10 days and nights, practically without stopping. During this period each well yielded 110 gallons per minute, and the water level was temporarily lowered 3 feet.[1] The water is used extensively on locomotive engines and for other purposes, train loads being shipped to points more than 50 miles east. Altogether, the consumption from these wells amounts to about 350,000 gallons per day, or 400 acre-feet per year.

The irrigation well of E. A. Von de Veld, SE. ¼ sec. 21, T. 5 N., R. 8 E., is 8 feet in diameter and 35 feet deep, with water level about 23 feet below the surface. This well will furnish about 80 gallons per minute, but the yield can no doubt be much increased by sinking deeper. The well of the Willard Mercantile Co., in the village of Willard, which is 5½ feet in diameter and 48 feet deep and in which the water level is 42 feet below the surface, has been tested at 40 gallons per minute.

The open well of L. Knight, NE. ¼ sec. 1, T. 5 N., R. 8 E., is about 45 feet long and 9 feet wide, and extends to a bed of gravel that is 32 feet below the surface and 10 feet below the water level. It yields about 90 gallons per minute. Several wells have also been drilled to greater depths, and, though they have not yet been tested, the beds of water-bearing gravel that they penetrated give promise of more generous yield.

The well of R. N. Reagan, SW. ¼ sec. 2, T. 6 N., R. 8 E., is a dug hole, 6 feet by 4 feet, to a depth of 31 feet, below which it is an uncased 12-inch drilled hole that goes to 115 feet beneath the surface. The section consists chiefly of gravelly clay to a depth of 60 feet, below which "concrete" is reported. The water level is 16 feet below the surface, and downward from this level more or less seepage is received, although the strongest water horizons are reported to be at 60 feet

[1] The data in regard to the test were given by John Knowles, who has charge of pumping tests and construction for the railway company.

and at the bottom. When completed this well was reported to have been pumped at more than 100 gallons per minute, which rate of pumping lowered the water level about 16 feet, but when tested in the summer of 1909 it yielded scarcely 40 gallons per minute with the same lowering of the water level. The well of Mr. Hawkins, sec. 14, T. 6 N., R. 8 E., is also reported to have been tested at about 100 gallons per minute.

On the premises of Mrs. Angus McGillivray, in Estancia, two test wells were put down—a 6-inch well to a depth of 37 feet and a 10-inch well to a depth of 233 feet ending in hard rock. According to the driller, the largest supply of water was found at a depth of 33 feet where the drill entered a 4-foot bed of gravel, from which the water rose to a point 5 feet below the surface. With a suction pipe extending 16 feet below the water level, the 6-inch well was successfully pumped at a rate approximating 200 gallons per minute.

In the test wells 4 miles east of Estancia the most water was found, according to J. L. Mayo, the driller, in a bed of gravel at a depth of about 215 feet, but pumping 15 gallons per minute from this source is said to have lowered the water level in the well considerably. The well of Oscar Hadley, 3 miles north and 4 miles east of Estancia, which is 94 feet deep, is reported to have been tested at about 20 gallons per minute without lowering the water perceptibly. The well of B. W. Honnold, SE. ¼ sec. 21, T. 7 N., R. 9 E., which is 140 feet deep, is reported to have been tested at 18 gallons; the 6-inch well of P. M. Rutherford, SW. ¼ sec. 27 in the same township, which is 104 feet deep, at 40 gallons; and the well of Mr. Campbell, about 5 miles northeast of Estancia, at 40 gallons. Several other tests of this kind were reported. On a number of the old ranches water has in the past been pumped from wells with steam engines.

Many wells, especially the dug wells on the alluvial slopes, end in clay from which the water seeps. Many others, in particular the cased wells in the central portion of the valley, end in fine sand, which, though yielding more freely than the clay, likewise gives up its water with difficulty and tends to fill the well whenever rapid pumping is attempted. Neither material can be relied upon to furnish water in abundance. For successful wells yielding large supplies it is in general necessary to find beds of gravel, and the coarser and cleaner the gravel the more successful will be the wells. Under "Geology," page 17, it was explained that the beds of gravel have little continuity or regularity, and that a bed encountered in one well may be entirely absent in another not far distant.

YIELD OF WELLS IN THE ROCK FORMATIONS.

Many wells, especially those near the mountains, end in rock. On the east side the water-bearing rock consists chiefly of sandstone, but on the west side limestone is more abundant. The yield of

these wells is ordinarily adequate for culinary purposes and for the use of stock, but such tests as have been made do not promise large supplies. At Mountainair one 8-inch railroad well yields 18 gallons per minute, and another railroad well only 14 gallons, while the 6-inch town-site well yields 28 gallons per minute. Each of the wells is more than 300 feet deep and in each the stated rate of pumping lowers the water level approximately 100 feet. In the test wells east of Estancia little water was found after rock was encountered. At the box factory, in the north part of Estancia, a well 6 inches in diameter and 120 feet deep was pumped at the rate of 18 gallons per minute, the water being lowered about 35 feet. The well of H. C. Williams, NE. ¼ sec. 26, T. 6 N., R. 8 E., is perhaps the best rock well that was reported. Below the depth of 233 feet it is said to pass through 70 feet of soft sandstone, and pumping at the rate of 40 gallons per minute is reported to have lowered the water in the well only 12 feet. In the last two wells mentioned there is some doubt as to whether the water comes from rock strata.

AVAILABLE QUANTITY OF GROUND WATER.

The rate at which wells yield water is a question of vital importance in determining the feasibility of recovering ground water on a large scale, but, contrary to the general supposition, it gives little information as to the total quantity available. This quantity is not inexhaustible, as is so freely assumed. So far as large pumping operations, such as would be required for extensive irrigation, are concerned its limits are sharply drawn. The amount of ground water obtainable can not be determined by pumping a few hundred gallons per minute from a well for a short period, for the same reason that the quantity of water in a lake can not be determined by applying to it the same pump; and to proceed on the theory that an unlimited amount of ground water is available for irrigation is as unwise as to plan an irrigation project without reference to the flow of the stream upon which it depends. The essential difference is that the flow of the stream can be readily and accurately measured, but no such precise methods can be applied to ground water, and therefore much more caution must be used in carrying out a project that depends upon ground water.

Some idea of the total quantity of water that is stored underground can be obtained by considering the sections of wells that have been drilled. The average thickness of the water-bearing beds can be multiplied by the total area over which they occur, and this product by the percentage of pore space in the material comprising these beds. But such an estimate will give little information that is of practical value because withdrawals in excess of the new contributions will lower the water level, increase the cost of pumping,

and eventually lead to disaster. Estimates of possible annual recovery by man must therefore be based on the annual increment or on the surplus annually disposed of by nature, and not on the total quantity now stored in the earth.

Unfortunately the quantity of water that is annually available in Estancia Valley can not be accurately predicted. From the discussion under the heading "Source and disposal" (p. 34), it appears that the surplus now disposed of by nature through evaporation from the salt basins and other areas of shallow water is a substantial quantity, probably amounting to many thousands of acre-feet each year. Perhaps most of this surplus could be intercepted in wells and pumped to the surface, but it can hardly be hoped that more than this surplus is annually available.

QUALITY.

SOLIDS DISSOLVED IN WATER.

The rocks which lie near the surface are exposed to weathering agencies that disintegrate and decompose them, thereby forming certain mineral compounds that are more or less soluble in water. The water which falls as rain contains little or no dissolved mineral matter, but when it enters the ground and percolates through the earth it gradually takes into solution those soluble substances with which it comes in contact, and consequently ground water always contains dissolved mineral matter. So long as this matter remains in solution it is invisible, but when the water is evaporated, as in a tea kettle or steam boiler or on the surface of the salt basins in Estancia Valley, it is left behind and forms a crust or scale. Ground waters differ greatly in the total amount of substances they contain in solution and in the proportions of the different kinds of substances. When, by evaporation of the water or some other cause, these substances are thrown out of solution, they form mineral salts, such as calcium carbonate (limestone), calcium sulphate (gypsum), sodium carbonate (black alkali), sodium sulphate (Glauber's salt), and sodium chloride (common salt).

METHODS OF INVESTIGATION.

During the progress of the field work 84 samples of water were collected and examined for their content of the carbonates, bicarbonates, sulphates, and chlorides. They were chosen from those wells or other sources which would aid most in interpreting the quality of the ground water for the entire region. They were obtained from all parts of the valley, but were taken in largest numbers in the central area, where the mineral content varies greatly within short distances and where its consideration is important in connection with irrigation.

The assays were made in the field by means of the apparatus and methods described in Water-Supply Paper No. 151. In order to have some check upon the work, and also to have a basis for judging the relative amounts of calcium, magnesium, sodium, and potassium, a single sample was sent to Prof. J. R. Bailey, of the University of Texas, for complete analysis in the laboratory. This sample was taken from the well of H. N. Summers, 6 miles east of Estancia, in the region where it was especially desirable to know the relative amounts of the bases in the deeper waters. The following table gives the complete analysis, and, for purposes of comparison, the field assay of a sample taken from the same well on the same day:

Analysis and field assay of water from well of H. N. Summers, 6 miles east of Estancia.

Ions.	Parts per million.	
	Sample assayed in the field.	Sample analyzed in the laboratory.
Total solids		1,956
Silica (SiO_2)		19
Iron (Fe)		.05
Aluminum (Al)		Trace.
Calcium (Ca)		200
Magnesium (Mg)		114
Sodium (Na)		274
Potassium (K)		3.8
Carbonate radicle (CO_3)	.0	.0
Bicarbonate radicle (HCO_3)	243	306
Sulphate radicle (SO_4)	553	755
Chlorine (Cl)	393	390
Temporary hardness as $CaCO_3$		251
Free carbon dioxide (CO_2)		8.8

The field determination agrees closely with the laboratory analysis in the content of chlorine, but there are considerable discrepancies in the bicarbonate and sulphate determinations. The bicarbonate determination is a simple volumetric process with a definite end point, and the assays probably gave results that are fairly accurate relative to each other. Despite these discrepancies, the field assays are of value, especially in throwing light on the problem of the utility of the water for irrigation, a problem in which it is desirable to have tests from as many localities as possible, but in which great precision is not required.

In the table on page 71 are given the results of the 84 field assays and also of 19 tests of water from railway wells, furnished by the Atchison, Topeka & Santa Fe Railway Co.

CHLORINE.

In general the chlorine content of these waters is proportionate to the amount of common salt that would be deposited by their evaporation. The ground waters of Estancia Valley differ widely in this

respect, the samples analyzed ranging from 7 parts to 16,442 parts per million in the amount of chlorine that they contain. In the central portion of the valley, where the amount of chlorine decreases with the depth, only tests of shallow water are shown on the map, the analyses of samples from deeper cased wells not being used for this purpose.

The analyses plotted on the map show the following conditions: First, the water underlying the western slope (including nearly all of the western alluvial slope and most of the littoral zone) contains small quantities of common salt, the chlorine content being uniformly less than 25 parts per million; second, in this large area the amount of salt does not increase notably from the foothills toward the center; third, throughout an area in the center of the valley the chlorine content is very great, some of the shallow water being so salty that it can not be used for watering stock; fourth, between the first and the second areas there is a zone of fairly pure water which averages about 3 miles in width but has a tendency to extend some distance up the arroyos; and fifth, the water is somewhat higher in its content of salt on the east side of the valley than on the corresponding west slope. The transition from the fairly pure water of the intermediate zone to the strongly saline water in the central area is remarkably abrupt, so that on the west side, where there are many wells, it was possible to outline with considerable accuracy the limits of the area in which the water has more than 1,000 parts of chlorine. The abruptness of this transition is shown by assay No. 59 (J. B. Striplin) and assay No. 61 (J. W. Kooken), given in the table (p. 72). The first sample, coming from a well in the intermediate area, showed only 219 parts of chlorine; the second, taken from a well a quarter of a mile farther east, showed 5,276 parts.

In the central area the shallowest water is the most strongly saline, and the water from deeper sources is, as a rule, much better. However, no definite law of variation with depth could be established, and it is altogether probable that in some of the deeper wells a certain amount of shallow saline water is admitted by imperfect casing and mingles with the deep water that forms the principal supply. Within the area in which the shallow water contains more than 1,000 parts, 9 samples were taken from cased wells in which, as far as could be ascertained, the water came from more than 25 feet below the groundwater level. In these 9 samples the chlorine content ranged from 234 parts to 932 parts and averaged 595 parts, whereas 6 samples of shallow water within the same area ranged from 1,165 parts to 16,442 parts and averaged 7,063 parts, or more than 12 times as much as in the deeper waters. These relations are shown graphically in figure 7.

Finally, it is important to note that the deep waters in the central area are much saltier than the waters from the wells on the surrounding slopes. Thus, 34 samples were taken on the west side of the valley in the area of less than 25 parts per million, which includes nearly all of the extensive region lying west of the New Mexico Central Railroad. In these 34 widely distributed samples the chlorine content ranged from 7 to 25 parts and averaged 16 parts, a result which should be compared with the assays of the nine samples of

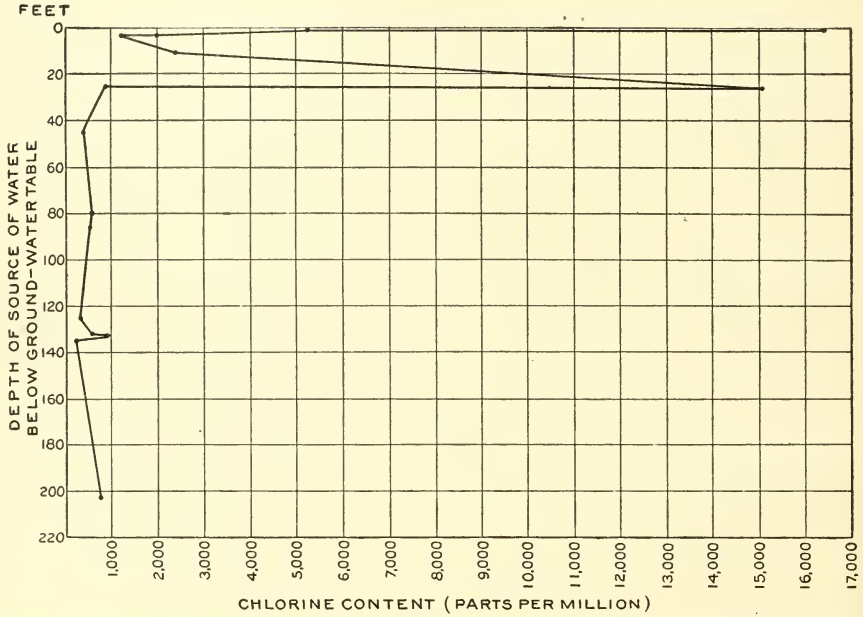


FIGURE 7.—Diagram showing decrease of chlorine with increase in depth of the waters of the central area of Estancia Valley.

deep waters in the central area in which the chlorine ranged from 234 to 932 parts and averaged 595 parts, or 37 times as much.

CAUSE OF SALINITY.

The salinity of the water in the central area results from the process described under "Source and disposal." The ground water is constantly being replenished at the borders by rainfall; responding to the force of gravity, it constantly moves valleyward; and in the low central area the accumulating surplus is constantly coming to the surface and being disposed of by evaporation. In its migration through the earth it picks up a load of salt which it takes into solution, and when it evaporates it leaves this salt behind, thus adding to the salinity of the remaining water or to the amount of alkali in the soil.

But the precise reason for the existing conditions is not so evident. In most of the area in which the sheet of saline water occurs the ground-water level is too far below the surface for capillarity to be effective in drawing up ground water within the reach of evaporation. Thus, in the wells from which were taken the six samples that were tested, the depth to water ranges from 7 to 36 feet, while capillarity is probably not effective for depths of more than 5 feet and quite certainly not for depths of more than 10 feet. Moreover, the salts drawn up by capillary action would be deposited near the surface where evaporation would occur, and how they would be carried back to contribute to the salinity of the ground water is not obvious. It is also necessary to account for the salt content in the deeper waters at the center. The most reasonable hypothesis is that at various horizons in the valley fill of the central area there are beds impregnated with salt deposited by evaporating waters at the time they were formed, and that afterwards these beds became buried under new accumulations of valley fill. It is not unlikely that the shallow sheet of brine coincides approximately with a buried salt deposit laid down at the bottom of the ancient lake at a certain stage of its existence. This hypothesis would also explain the sharp boundary of the area.

SULPHATES.

The amount of the sulphate radicle in these waters is a measure of the sodium and calcium sulphates that they deposit on evaporation. The field apparatus can not well be used for determining less than 30 parts or more than 625 parts per million of this constituent,[1] but the waters in Estancia Valley range from less than this minimum to considerably more than this maximum. On the map (Pl. XI) the sulphate content is shown by blue figures, letters, and lines. Samples that contained less than 30 parts are represented by the letter "S," samples that contained between 100 and 625 parts are represented by the letter "M," and samples that contained more than 625 parts are represented by the letter "L." Only for those samples that come between 30 and 100 parts are the parts per million given in numbers, because it is only within this range that the field determinations have considerable accuracy. As with chlorine, the tests of samples from deeper cased wells are not plotted on the map.

With certain exceptions, the distribution of sulphates is analogous to that of chlorine, and the reasons for this distribution are no doubt in general the same. The western slope is underlain by water that has a small sulphate content, and in which there is no noticeable increase of sulphates toward the center, but the central area is

[1] If water containing more than 625 parts is diluted with distilled water, its content of sulphate can be determined. This was done with the samples from Encino and Pinos Wells. See pp. 71 and 83.

underlain by water that is rich in sulphates, and between these two areas is a narrow intermediate zone. Then, too, the sulphate content is greater on the east side than on the corresponding west slope, and the deep water in the central area contains less sulphate than the shallow water in the same area, though much more than the water that underlies the west slope.

An important exception to the parallelism between the chloride and sulphate contents, however, is found in the southwestern part of the region, where the ground water contains a large amount of sulphates, but only small quantities of chlorides. This condition is well shown on the map (Pl. XI) by the radical divergence of the chloride and sulphate lines when they reach the south end of the valley. The large sulphate content is clearly due to the presence of gypsum in the derivative rocks, for in the escarpment of the Mesa Jumanes a bed of gypsum 100 feet thick is exposed. It will be observed that the effect of this gypsum bed does not extend far north, which is another indication that the principal ground-water supply comes from the western mountains.

CARBONATES AND BICARBONATES.

None of the samples that were tested showed an alkaline reaction with phenolphthalein, which fact shows the general absence in these waters of the carbonate radicle and hence of sodium carbonate, the injurious black alkali. This is not surprising, in view of the abundance of gypsum, which reacts with sodium carbonate and precipitates the carbonate radicle in the form of calcium carbonate. The phenolphthalein test does not prove the absence of sodium bicarbonate, but the abundance of gypsum does not favor its presence.

In the samples that were tested the bicarbonate radicle ranges from 97 to 873 parts per million, a much smaller range than that of the chloride and sulphate radicles. The chlorides and sulphates are much more readily soluble than the carbonates, which, together with the carbon dioxide present in the water, produce bicarbonates. Nevertheless, in the deposits on the west slope, except at the south end, chlorides and sulphates are so rare and carbonates (limestones and calcareous cement) so abundant that the water beneath the west slope contains much larger amounts of the bicarbonate radicle than of the chloride and sulphate radicles. But as the water percolates through the buried lake beds or other deposits in the central areas that are impregnated with salts, it redissolves large quantities of the soluble chlorides and sulphates, but only minor quantities of the carbonates, because it has already taken them up almost to the point of saturation; hence, in the central area the relative amounts of these ingredients are reversed, the total of bicarbonates being nearly the same, but the sulphates and chlorides having increased enormously.

BASES.

The principal bases, or positive radicles, are calcium, magnesium, sodium, and potassium. The relative amounts of these were not determined in the field, but the following inferences can be made. In the less highly mineralized water on the west slope, calcium and magnesium, derived from the carbonates, predominate greatly over sodium, while in the water near the south end, and to some extent also on the east side, the principal base is calcium derived from the sulphate; but in the central area large quantities of sodium chloride are taken up, thus increasing the content of sodium, so that in the strongly saline waters sodium is much more abundant than calcium or magnesium. Moreover, sodium sulphate is more soluble than calcium sulphate, which fact also tends to increase the relative amounts of sodium in the central area.

EFFECTS OF DISSOLVED SOLIDS.

Small amounts of the constituents commonly found in natural waters are not harmful to health. Chlorides are not objectionable in drinking water if only 50 to 100 parts are present, but amounts clearly preceptible to the taste render water unpalatable. Magnesic or sodic sulphated waters are laxative, and excessive magnesium or sodium content renders water unfit for man or beast. The worst form of alkali water—that containing alkaline carbonates—was not found in this region.

Calcium and magnesium render water hard and therefore poor for toilet and laundry uses. Bicarbonates and an equivalent quantity of calcium and magnesium are removed from water by boiling, but the calcium and magnesium in excess of this amount, such as would be present in gypsiferous waters, can not be precipitated by boiling. Sodium and potassium do not consume soap and therefore do not make water hard.

Calcium and magnesium compounds are the principal constituents of boiler scale. Sodium and potassium compounds do not form scale, but when they occur in large quantities they cause foaming and priming in boilers.

Water with relatively large amounts of most kinds of dissolved mineral matter is tolerated by plants. Among the common sodium salts the most injurious is sodium carbonate and the least injurious sodium sulphate; sodium chloride occupies an intermediate position. The effect of dissolved solids in irrigation water is more fully discussed under the next heading—"Irrigation."

IRRIGATION.

Much of the water that falls as rain or snow is lost or is of very small service in producing vegetation useful to man. If only a small part of this water that is now lost can be recovered and applied to growing crops it will greatly increase the agricultural product of the valley. Recovery is possible by storing storm water and by recovering ground water.

STORAGE OF STORM WATER.

The floods that from time to time come down the large arroyos and spread out over their extensive flat bottoms provide a sort of natural irrigation which makes these arroyos the most fertile and productive portions of the valley, and for this reason they bear such appropriate names as Arroyo Mesteño (Ranchers' Draw) and Arroyo Fecundo (Fertile Draw). The utility of this flood water could be increased if it were stored in reservoirs and applied in an economical manner at the time it is most needed. Only small beginnings in this direction have thus far been made, and without doubt further development would be found profitable, although there are handicaps in the scarcity of good reservoir sites and in the capricious nature of the floods.

UTILIZATION OF GROUND WATER.

PRESENT DEVELOPMENT.

At the time the valley was visited, in the summer of 1909, little had been accomplished in the way of irrigating with ground water, although a number of gardens and other small plats were being irrigated from this source by means of windmills, and somewhat more ambitious projects were being undertaken by S. Spore, L. Knight, E. A. Von de Veld, and H. C. Williams.

The plant of S. Spore is located 3 miles east of Estancia, on sec. 9, T. 6 N., R. 9 E. The water is provided by a large hole dug 23 feet below the surface, or about 15 feet below the water level, and one or more deeper drilled wells which discharge into the bottom of the dug hole. It is lifted by a chain and bucket elevator whose capacity is rated at 800 gallons per minute, the power being furnished by an 8-horsepower gasoline engine. The plant was not seen in operation. It was reported that considerable water had been developed, but that it is saline in character.

The plant of L. Knight is located 4 miles south of Estancia, on the NE. $\frac{1}{4}$ sec. 1, T. 5 N., R. 8 E. A hole, about 45 by 9 feet in size, has been dug 32 feet below the surface, or about 10 feet below the water level, and several deeper wells have been drilled. The yield of the dug well is about 90 gallons per minute; the drilled wells had not been

tested. The water is lifted from the dug hole into an earth reservoir by means of a chain and bucket elevator propelled by a gasoline engine. The capacity of the elevator is rated at 250 gallons per minute and the engine at 4½ horsepower.

The plant of E. A. Von de Veld is located 7 miles northwest of Willard, in the SE. ¼ sec. 21, T. 5 N., R. 8 E. The water is obtained from a well 8 feet in diameter and 35 feet deep, which extends about 12 feet below the water level, and will yield about 80 gallons per minute. The water is lifted by a chain and bucket elevator propelled by a gasoline engine. The capacity of the elevator is rated at 160 gallons per minute.

The farm of H. C. Williams, 2½ miles south of Estancia, is in the shallow-water belt, and a ditch has here been dug for the purpose of leading the ground water out upon lower land by gravity. In the deep well the water rises to within 3½ feet of the surface. No pumping plant has been installed.

POSSIBILITIES OF FUTURE DEVELOPMENT.

The data already given seem to indicate that without seriously depleting the present supply, enough water can be withdrawn annually from the underground reservoir to increase materially the total production of the valley, but that, on the other hand the supply is not sufficient to irrigate more than a small part of the total acreage of arable land. If it is once proved that pumping for irrigation is feasible and profitable, the danger of overdevelopment will become imminent.

PROPER TYPE OF IRRIGATION SYSTEMS.

Irrigation with surface water has necessitated large cooperative projects, but the problem of irrigating with ground water, even on a large scale, is essentially different. In Estancia Valley each farmer should develop his own supply, install his own pumping plant, and construct his own reservoirs and system of distribution. This method of development will insure a maximum supply with a minimum lowering of the head, and will involve the least lift and the least loss in distribution. The only respect in which cooperation may be found profitable will be in the installation of a central power plant.

PROPER TYPES OF WELLS.

Where large supplies are required, as for irrigation, they can best be obtained by drilling in search of thick beds of clean, coarse gravel that will yield freely, sinking, if necessary, at least to the bottom of the valley fill. There are three reasons why deep-drilled wells are likely to yield much more water than shallow wells that stop a short dis-

tance below the ground-water level—first, the thickest and best beds of gravel may occur at any depth and the probabilities are, therefore, that they will not be found by shallow wells; second, of two similar beds the one at a considerable depth below the ground-water level will yield much more than the one only slightly below this level, because the water in the deeper bed is under much greater artesian pressure; third, if a deep well is properly finished with perforated casing, it can simultaneously receive supplies from all water-bearing beds that it penetrates.

If a single well will not yield enough, a group of wells can be drilled. A large pump can then be inserted at the bottom of a centrally located pit dug to the ground-water level or somewhat lower, and suction pipes from all the wells can be connected with it; or, if it is desired to use a chain-and-bucket elevator, the central pit can be sunk to a considerable depth below the ground-water level and the drilled wells can be connected by horizontal tunnels or pipes with the bottom of the pit, into which they will then discharge. Since the cost of pumping increases with the lift, it will be economy to have so many wells that the water in them will not be greatly lowered by pumping. In either system above described some expense will be involved in connecting the various wells.

For large supplies, beds of very fine sand should be cased out, because this sand yields its water slowly and causes trouble by rising in the wells. Screens can be employed to shut out the sand more or less effectually, but they are likely to become clogged in a short time and to require much attention. Difficulty with sand in wells can be reduced to a minimum by pumping slowly or by having a large number of wells so connected that water is drawn only at a slow rate from each.

Where no satisfactory water-bearing bed can be found and where the shallow water is not saline, it may be possible to develop valuable supplies from large dug wells or from systems of infiltration galleries, or it may be feasible to bring up the total yield by combining these with deep wells. If possible the maximum yield of the system of wells should be kept much greater than the capacity of the pumps, as this will reduce to a minimum the cost of lifting the water, the wear and tear of the machinery, and in some cases the deterioration of the wells.

GRAVITY INFILTRATION DITCHES.

The fact that it is possible to lead water by gravity from the shallow-water belt on the west side out upon lower ground to the east makes this scheme for irrigating appear very attractive, but it is not believed that enough water can be recovered in this way to justify the necessary expense of construction. The same money will

be better invested in wells and a pumping plant with which a larger, more reliable, and more elastic supply can be obtained. Prof. Slichter discusses ditches of this type and makes the following concluding statements:[1]

It should be noted that very few infiltration or underflow canals are in actual use for irrigation purposes. There are many pumping plants in use for irrigation which have turned out to be both practicable and financially profitable; but the attempts to secure ground water by gravity have usually proved disappointing, and there are numerous abandoned underflow canals in many parts of the West.

COST OF PUMPING.

In estimating the cost of the water it is necessary to take into account the original cost of the wells, pumps, engines, reservoirs, ditches, and other equipment, and the cost of operation, which includes fuel, oil, repairs, labor, and other items. In considering the original cost as a factor in the cost of a unit quantity of water, it is most convenient to estimate the amount of deterioration of the plant in one year and to add this to the annual interest on the total amount invested in the plant. The sum should then be divided by the number of units of water pumped in a year. Prof. Slichter advises that the charge for depreciation and repairs should not be estimated at less than 10 per cent of the first cost of the plant.

The following tables give the results of a number of tests of small pumping plants in Arkansas Valley, Kans.,[2] and in the Rio Grande valley, N. Mex.[3]

Tests of small pumping plants, Arkansas Valley, Kans.

Kind of pump.	Horsepower of engine.	Fuel used.	Price of fuel per gallon.	Total lift.	Yield of well per minute.	Cost of fuel per acre-foot[4] of water.	Cost of fuel for each foot that an acre-foot is lifted.
				Feet.	*Gallons.*		
No. 3 centrifugal	6	Gasoline	$0.22	22.1	272	$2.93	$0.13
Menge	10	do	.20	15.5	394	2.90	.19
Two vertical, 6 by 16 inch cylinder.	1½	do	.22	15.06	91	3.75	.25
Chain and bucket	7	do	.21	17.0	540	1.37	.08
Do	2½	do	.22	15.8	215	2.78	.18
No. 4 centrifugal	10	do	.12½	22.13	363	2.10	.09
No. 3 centrifugal	6	do	12½	17.60	198	1.67	.09
No. 14 centrifugal	80	Coal	[5] 4.00	23.00	2,300	.85	.04
Two horizontal, 5 by 5 inch cylinders.	3½	Gasoline	.12½	21.7	96	1.09	.05
No. 4 centrifugal	5	do	.12½	21.47	420	1.20	.06

[1] Water-Supply Paper U. S. Geol. Survey No. 184, 1906, p. 22.
[2] Slichter, C. S., The underflow in Arkansas Valley in Western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, pp. 55 and 56.
[3] Slichter C. S., Observations on the ground waters of Rio Grande Valley: Water-Supply Paper U. S. Geol. Survey No. 141, 1905 pp. 34 and 35.
[4] An acre-foot contains 325,850 gallons of water, which is enough to cover 1 acre to the depth of 1 foot.
[5] Price per ton.

Principal data derived from tests of Rio Grande pumping plants.

Horsepower.	Fuel used.	Price of fuel.[a]	Total lift.	Yield per minute.	Cost of plant.	Interest and depreciation per hour.[b]	Labor and other cost per hour.	Fuel cost per acre-foot.	Total cost per acre-foot.
			Feet.	*Gallons.*					
10	Electricity	$0.05	38.93	378	$1,200	$0.108	$0.050	$3.43	$5.75
8	Gasoline	.14	39.70	269	800	.072	.120	2.26	6.13
5½	....do	.14	27.80	258	800	.072	.140	1.58	6.02
28	Crude oil	.03	36.70	938	3,000	.270	.180	.70	3.17
22	Gasoline	.14	41.45	1,325	2,200	.198	.150	1.43	2.79
15	....do	.14	35.87	658	1,500	.135	.150	1.73	4.10
5	....do	.17	45.58	131	1,200	.108	.120	3.73	13.20
12	....do	.17	40.30	658	1,200	.108	.150	1.34	3.47
21	....do	.17	40.45	725	1,800	.162	.150	2.52	4.87
8	....do	.17	26.85	648	900	.081	.120	1.48	3.16
12	....do	.17	34.77	325	1,200	.108	.150	5.14	9.57
8	....do	.17	36.05	271	800	.072	.120	5.10	8.95
10	Wood	2.00	34.16	351	1,200	.108	.180	3.47	7.91
28	Gasoline	.17	43.35	464	2,000	.180	.150	4.34	8.19
20	Wood	2.25	29.55	1,000	1,600	.144	.200	2.83	4.70
12	Gasoline	.17	23.89	837	992	.090	.090	1.04	2.21
12	....do	.17	35.26	191	992	.090	.090	5.80	10.90
12	....do	.17	32.36	750	992	.090	.090	1.16	2.46

[a] The price of gasoline given is for 1 gallon, the price of electricity for 1 kilowatt-hour, the price of wood for 1 cord.
[b] The depreciation and repairs are calculated at 10 per cent of the original cost and the interest at 8 per cent.

As nearly as can be estimated from rather indefinite data obtained in regard to the plant of E. A. Von de Veld, northwest of Willard, the cost for fuel is about $3.50 per acre-foot. The water is here lifted with a 160-gallon chain and bucket elevator, the average lift being about 30 feet, and the price paid for the gasoline was reported to be 31 cents per gallon. According to these data, for each foot that an acre-foot of water is lifted the cost is about 11⅔ cents and the consumption of gasoline about 0.38 gallon. With the present capacity of the well, one-fifth of an acre-foot can be drawn conveniently in one full day; and on this basis if the plant is operated 100 days it will consume $65 worth of gasoline and provide enough water to cover 20 acres to a depth of 1 foot or 10 acres to a depth of 2 feet. With gasoline bought at minimum wholesale prices and with more careful adjustments between the capacities of engine, pump, and well, the cost for fuel can be reduced materially, but the above figures are believed to be valuable in giving an idea of what has been done in practical work.

In a discussion of the cost of pumping in Arkansas Valley, Kans., the following statement is made by Prof. Slichter in regard to gas-producer plants:

> If plants of from 20 to 50 horsepower are constructed, as I believe will inevitably be the case in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines. These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less than one-half cent per horsepower for one hour, or only one-fifth of the cost of power from gasoline at 22 cents a gallon. The writer anticipates no difficulty, therefore, in

keeping the cost of water below 60 to 75 cents an acre-foot for fuel, or below $1.25 to $1.50 per acre-foot for total expense.[1] Hundreds of such plants have been put in use in England during the past ten or more years, and they are in charge of unskilled labor. These gas-producer plants are used in England for a great variety of purposes, such as power for agricultural machinery and for small electric-light plants for country estates, etc. They are used in as small units as 5 horsepower.

In this country the producer-gas plants have been in use for several years, and at the present moment they are fast taking the place of steam power in new plants. The cost of a producer plant and gas engine is about the same as the cost of a steam engine and boiler of same size when everything is included, but the cost of power from the producer-gas plant is very much less than that obtained from small steam engines.

In producer plants ranging upward from 100 horsepower, a style of plant may be installed in which soft coal or lignite may be successfully used. This still further cuts down the cost of power. In fact, large plants of this type furnish the cheapest artificial power that has yet been devised. The saving is not only in fuel, but also in labor, as one man is capable of running a 300-horsepower plant.

In Estancia Valley gas-producer plants should be installed only after sufficiently large supplies of water have been developed to insure their success. A central power plant which will furnish an electric current for operating pumps on a number of farms may prove the most economical method of lifting water.

WINDMILLS.

Much has been written on irrigation with windmills. Their obvious advantage is that they utilize energy supplied by nature free of charge, but their original cost and the cost for oil and repairs are by no means negligible. Their greatest disadvantage lies in their dependence upon the wind, which may not blow at the time the water is most needed. They are best adapted to those parts of the valley where great depth to water or small yield permit of irrigation on only a small scale.

The following data, taken from the Yearbook of the Department of Agriculture for 1907, will give some conception of what can be done with windmills. If the lift is increased or decreased, the amount of water that can be pumped will be decreased or increased in about the same ratio.

Work done by a 12-foot windmill.

Velocity of wind in miles per hour.	Height water was lifted.	Quantity of water pumped per hour.
	Feet.	*Gallons.*
6	56	89.76
8	56	269.28
10	56	501.16
12	56	718.08
17	56	1,271.60
18	56	1,353.88

[1] It should be remembered that this statement is made for the Arkansas Valley, where the water is near the surface.

Work done by windmills of different sizes.

Size and type of windmill.	Time.	Average wind velocity per hour.	Height water was lifted.	Quantity of water pumped.	
	Days.	*Miles.*	*Feet.*	*Gallons.*	*Acre-feet.*
16-foot, direct stroke	45¼	12.98	56	752,967	2.31
14-foot, back geared	45¼	12.98	56	666,991	2.05
13-foot, back geared	45¼	12.98	56	502,207	1.54
12-foot, back geared	45¼	12.98	56	408,854	1.25

Under "Climate" is given a table that contains data in regard to the average wind velocity of the region. It should be understood, however, that the efficiency of an average velocity is considerably different from that of a uniform velocity, because of the low efficiency both of very gentle and of very strong winds.

STORAGE AND DISTRIBUTION.

Large reservoirs are not feasible, and where the water is pumped at the cost of fuel they may not be desirable, because they involve loss both by evaporation and by seepage. Small reservoirs, on the other hand, are generally useful, especially for pumping plants of small capacity, because they diminish the labor necessary in applying the water to crops and also lessen the loss of water in the distributing ditches. Where windmills are used it is advantageous to have relatively large storage facilities.

Reservoirs made by banking up earth are least expensive, and they can usually be rendered nearly water-tight if they are puddled by driving cattle or sheep about in them. Obviously it will not do to store costly water in a leaky reservoir, and possible loss through leakage must be carefully guarded against.

The following information and advice in regard to the construction of small earth reservoirs is given in a recent bulletin by P. E. Fuller:[1]

> A means of storing water * * * should be resorted to in every instance where the flow is less than 600 gallons per minute. The reason for recommending a reservoir for flows up to this amount is that, with small streams used direct from the pumps, the loss in conveyance in ditches is excessive and the loss in the application of the water to the land is large, since a small stream will saturate a spot and a large amount of water will sink into the soil in this one place instead of spreading over a large area and moistening the surface. Further, much more labor is required to irrigate with a small stream than with a large one. * * * The reservoir should be of sufficient size to hold the water pumped between irrigations.
>
> The following table gives the dimensions of circular reservoirs of different capacities; the quantities of earth in the embankments, if these have inside slopes of 3 to 1 and outside slopes of 1 to 1; the areas which can be irrigated, provided the reservoir

[1] Fuller, P. E., The Use of Windmills in Irrigation in the Semiarid West: Farmers' Bull., U. S. Dept. Agr., No. 394, 1910, pp. 28 to 33.

full of water is used once in ten days throughout five months and the land receives water to a depth of 1 foot; and the costs of the reservoirs:

Sizes of circular reservoirs and estimated cost for various areas of land to be irrigated.

Gross capacity of reservoir.	Depth of reservoir	Diameter at bottom of embankment.	Diameter at top of embankment.	Bottom width of embankment.	Top width of embankment.	Amount of fill required.	Estimated cost of reservoir.	Area irrigated.
Acre-feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Cu. yds.*		*Acres.*
0.07	4	21.30	45.30	19	3	212.00	$21.20	1
.16	4	34.96	58.96	19	3	281.52	28.15	2
.24	4	45.62	69.62	19	3	336.25	33.62	3
.32	4	54.61	78.61	19	3	381.88	38.18	4
.40	4	62.27	86.27	19	3	422.46	42.24	5
.49	5	58.58	88.58	24	4	684.71	68.47	6
.56	5	63.64	93.64	24	4	725.80	72.58	7
.63	5	69.00	99.00	24	4	747.75	74.77	8
.72	5	74.37	104.37	24	4	813.51	81.35	9
.80	5	79.36	109.36	24	4	854.16	85.41	10

If possible a site should be chosen where the natural surface of the ground which will become the bottom of the reservoir is above the land to be irrigated, and if the highest land to be irrigated is some distance from the reservoir the bottom should be enough higher than the land to give a slope of at least 6 feet to the mile from the reservoir to the land.

All sod and vegetation should be removed from the site, as the decay of the roots will leave passage for seepage. In a circle midway between the outside and inside bank line plow a trench 2 feet wide and 1 foot deep, removing this dirt to the outside of the bank; fill in this trench with clay, or with a clay and gravel mixture. After a part of the trench has been so filled add water, and thoroughly puddle so as to form a bond between the original walls of the trench and the material added; haul in additional clay material to this section of the trench until it projects above the original ground surface at least a foot and is yet a soft mass; then proceed to build the banks, puddling and tamping the new fill so as to thoroughly bind with the core of clay material. Proceed with the embankment until the first course to a depth of 6 inches has been completed around the entire inclosure, then add a second course of the same thickness around the entire wall, allowing the teams to walk upon the top of the banks a distance of at least 20 feet each time a scraper is dumped, for in this way each course is well tamped as the work progresses. It would be far better if each course could be thoroughly wet down so as to puddle it or better to tamp the embankment; and even better results would be obtained if the clay core could be carried up with the work to the top of the bank, though this is not an easy matter and is not imperative if the material used in constructing the banks is of a clayey nature. It is well to allow the banks to settle under several rains or snows before the reservoir is filled.

The inside slope of the bank should be very gradual, so as to avoid erosion and cutting. The width of the top of the bank should be not less than 3 feet for a reservoir 4 feet deep, and 4 feet for one 5 feet deep. The slope of the outside of the embankment may be steeper, 1 to 1 if planted to grass, so as to avoid washing or cutting from rains.

Haul into the bottom a lining of clay or clay mixture several inches in excess of the depth of soil removed, and after distributing it evenly pump into the reservoir sufficient water to form a thick muck or paste and thoroughly puddle by keeping cattle or sheep in the reservoir for at least a week, and better for thirty days. Indeed, the entire success of the reservoir is dependent upon such puddling, and there can be no reason why, by placing a temporary fence around the inclosure, the cattle or sheep

can not be fed and watered while so penned up for thirty days. It will of course be necessary to allow water to run into the reservoir in small quantities during the operation of puddling, so as to maintain a soft puddle. After the work of puddling is completed the banks may be trimmed to line by shovel.

The inlet and outlet pipe should be put in place while the banks are being constructed, for in this manner a water-tight joint between the pipe and banks can be secured.

The loss from evaporation in the reservoir can be reduced effectually by the planting of bush willows or some similar low-bush tree profusely around the top of the banks, thereby breaking the wind. The cutting of banks from wave motion can be eliminated entirely in an earthen reservoir by floating a boom of old railroad ties or other timbers around the inner banks facing the direction of the prevailing wind, or, if desirable, around the entire reservoir. The ties should be held together at the ends by cleats securely nailed and the entire boom should be anchored in a line 3 feet from the banks.

VALUE OF CROPS.

Intensive cultivation of crops that yield large returns per acre would, of course, leave the largest margin after the cost of the water is deducted and would thus guarantee the surest success for irrigation by pumping, but present calculations must be based on such ordinary field crops as can be depended upon in respect both to yield and market value. It is not intended here to enter into a full discussion of the various crops that might be raised, but rather to state a few facts which will give some quantitative basis for comparing crop returns with cost of water.

In regard to alfalfa, Samuel Fortier, chief of irrigation investigations in the Department of Agriculture, states:[1]

> Perhaps the most essential conditions for the production of alfalfa are abundant sunshine, a high summer temperature, sufficient moisture, and a rich, deep, well-drained soil. All of these essentials, save moisture, exist naturally in the arid region of the United States, and when water is supplied it makes the conditions ideal. * * * It is grown successfully in every State and Territory of the arid region, in localities which are not only widely separated but possess many radical differences in the way of rainfall, temperature, altitude, topography, and soil.

Mr. Fortier cites an experiment in Montana in which with 1 foot of irrigation water 4.42 tons of cured alfalfa per acre were produced, and with 2 feet, 6.35 tons, and adds:

> The results of this experiment seem to confirm the best practice of southern California, which may be summed up by stating that in localities having an annual rainfall of about 12 inches, remarkably heavy yields of alfalfa may be obtained from the use of 24 to 30 inches of irrigation water, providing it is properly applied.

C. A. Fisher[2] states that in the vicinity of Roswell, N. Mex., if 30 inches per year are properly applied, three or four crops of alfalfa may be cut, an average yield being 1 ton to the acre for each cutting. V. L. Sullivan, territorial engineer of New Mexico, estimates[3] that

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[1] Irrigation of Alfalfa: Farmers' Bulletin No. 373, U. S. Dept. Agr., 1909.

[2] Geology and underground waters of the Roswell Artesian Area, New Mexico: Water-Supply Paper No. 158, U. S. Geol. Survey, 1906, p. 28.

[3] Irrigation in New Mexico: U. S. Dept. of Agr., Bull. No. 215, 1909, p. 17.

"the yield of hay (alfalfa) in this part of the United States is 2 to 7 tons an acre when grown under irrigation; an average of 5 tons is a conservative estimate, usually producing a net return of $10 per ton." Alfalfa seed is a valuable though rather uncertain crop, but it requires little water and could perhaps be raised to advantage after one crop of hay had been harvested.

Good crops of wheat, oats, and other cereals could no doubt be raised by irrigation, but a given amount of water would probably accomplish more if applied to beans, potatoes, or forage plants such as cane, millet, and kaffir corn. Beets and other vegetables are said to thrive well when moisture is applied, and some kinds of fruit could be raised. Melons have been grown with good results.

BEST USE OF THE WATER.

The most hopeful view of the future of irrigation in Estancia Valley can not alter the conclusion that this valley must remain largely a grazing or dry farming region. Grazing yields very small returns per acre; dry farming may, if the elements happen to be propitious, yield vastly more. But the elements are capricious, and the farmer who must depend upon them entirely will of necessity have a precarious lot. The available water will, of course, be utilized in various ways, but it would seem that in the main it will be put to its best use when it is employed to supplement dry farming and stock raising.

In the first place, every farmer should irrigate a few shade trees, a small orchard, a small grass lawn, and a garden containing vegetables, shrubs, and flowers. These things will contribute much to the comfort of farm life, and, moreover, the garden will be of substantial value in supplying food for the household and in making it possible to tide over dry years. One of the very few examples of such irrigation at present found in the wide expanse of the valley is at the old Moriarty ranch. A small supply of water will prove sufficient; indeed, there are few localities in the valley where enough water can not be obtained or where it is so deep that the farmer can not afford to pump it for this purpose. For this kind of irrigation windmills will be useful, but it will be well to supplement them by small gasoline engines, so that the supply will not fail at the time it is most needed.

Where plentiful supplies of water are available within a comparatively short distance of the surface, it is believed that it can be made profitable to install a larger plant and to irrigate a number of additional acres, on which alfalfa or forage can be raised. These crops will have a high value if fed to the stock on the farm in the winter or in times of extreme drought, when otherwise the stock would suffer severely. A portion of the water may be used to raise for the market some more intensive crop, such as beans or potatoes, the proceeds of which will help to tide over years of failure in dry farming.

It may be that the ground water can be used to some extent to supplement dry farming directly. The damage to crops is due perhaps less to the absolute deficiency of rainfall than to its irregularity and uncertainty. Enough rain may fall throughout the growing season to produce a fair yield except in one period of drought. If during this period the ground could be given one good wetting the success of the crop would be assured, but the wetting does not come and the farmer is helpless to prevent the failure of his crop. Irrigation water at this critical time would have a value out of all proportion to that of its ordinary crop-producing power. It is evident that a relatively small amount of water, considered for the entire year, would cover a large acreage; and the farmer who has gone through the hard experience of seeing his entire crop ruined will readily appreciate that if, by means of the artificial application of water, even a small portion of his crop can be saved, it will be infinitely better than failure.

If the reader will turn to the records of precipitation given under "Climate" (p. 31) he can pick out for himself the months when artificial watering was necessary. Brief as the records are, they show that the crop-ruining months are sufficiently numerous to do heavy damage. They also show that while deficiency of rainfall is most common in the spring, when the crops ought to be started, it may strike any part of the growing season.

There will, of course, be difficulties in developing a feasible method of combining irrigation and dry farming, but there appears to be no inherent reason why such a combination method can not be evolved.

The limits to the area in which the larger use of water is practicable and the limits to the amount of irrigation that is possible in any given locality within this area must be determined gradually by experience. The situation tends strongly toward an economical use of the water, and economy will tend in two ways to enlarge the scope of irrigation. It will reduce to a minimum both the expense of pumping and the waste of the limited underground supply. The first concerns the immediate welfare of the individual; the second concerns the permanent welfare of the entire community. To a certain extent individual self-interest will here abet the public welfare, for the pumps will not be operated except when necessary.

THE ALKALI PROBLEM.

The answer to the question whether water of a certain quality can be successfully used for irrigation depends largely on a number of related conditions, among which may be mentioned the kind of crops to be raised, the amount of alkali already in the soil, the natural drainage of the land or the ease with which artificial drainage could be established, and the cost and abundance of the water itself. If

all of these conditions are favorable, water containing large amounts of sodium sulphate and sodium chloride can be used with success, but if all or most of them are unfavorable the case is entirely different.

During the summer of 1902, T. H. Means, of the Bureau of Soils, visited certain oases in Sahara Desert, in eastern Algeria, in which water carrying large quantities of soluble matter is used for irrigation with good results. Some of the vegetables successfully grown are those considered sensitive to alkali, and yet they were being irrigated with water containing, in some instances, as much as 8,000 parts per million of soluble salts, sometimes as much as one-half of these salts being sodium chloride. The methods used are described as follows:[1]

The Arab gardens are divided into small plats, about 20 feet square, between which run drainage ditches dug to a depth of about 3 feet. The soils being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is by the check method, and application is made at least once a week, though often two wettings a week are deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of the water downward is maintained, there is little opportunity for the soil water to become more concentrated than the water as applied, and the intervals between irrigations being so short but little accumulation of salt from evaporation at the surface takes place. What concentration or accumulation does occur is quickly corrected by the succeeding irrigation.

It is essential to note that the successful use of this water depends entirely upon good drainage conditions and the application of large amounts of water. In the same paper, Means says:

The limit for concentration for irrigation water in the United States, even where only the most resistant crops are to be grown, has been placed by some authorities at 300 parts sodium chloride (common salt) or sodium carbonate (black alkali) and at from 1,700 to 3,000 parts of the less harmful salts, per million of water.[2] Those who place the low limit of safety for alkaline irrigation waters have taught that where water was badly alkaline irrigation should be sparing. They have not insisted on thorough drainage, and they have warned irrigators against too frequent irrigation. With such practices the limit of concentration which they set is probably high enough, and even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged.

In regard to the same subject, C. W. Dorsey says:[3]

When the soil contains a relatively large amount of salt and but little water containing much salt is frequently applied, the ordinary evaporation will increase the salt content of the soil to such an extent that crops can no longer survive, whereas if adequate drainage is provided and a large amount of water is used the excess of salt resulting from the evaporation of previous applications of water may be removed and the soil moisture be maintained at nearly the same concentration as the water supply.

The data given under "Soil" and "Quality of water" furnish a basis for a rather definite conclusion in regard to the feasibility of irrigating in the alkali area of Estancia Valley. The samples of soil

[1] Means, T. H., The use of alkaline and saline waters for irrigation: Bureau of Soils, Circular No. 10, U. S. Dept. Agr.

[2] In the original paper the quantities are expressed in parts per 100,000 of water.

[3] Reclamation of alkali soils: Bull. Bureau of Soils, No. 34, U. S. Dept. Agr., 1906, p. 11.

that were analyzed have a high alkali content, and the water in the same region is rich in dissolved chlorides and sulphates. Within the area of saline shallow water (that is, the area in which the shallow ground water has a chlorine content of more than 1,000 parts per million) nine samples of deeper water were tested, and the average chlorine content of these samples was found to be 595 parts per million. On the assumption that all the chlorine is in equilibrium with sodium, the average content of common salt would be 982 parts per million, or more than 2,500 pounds per acre-foot. By the time 10 feet of water would have been applied to a field, 25,000 pounds of common salt would have been placed on each acre irrigated, a quantity equivalent to 0.625 of 1 per cent of the soil if concentrated in the first foot, or 0.156 of 1 per cent if distributed through the upper 4 feet.

If good drainage conditions could be established and water applied unsparingly, then, by the use of the deeper water, the alkali now in the soil and that introduced by the water could be disposed of by leaching it downward and draining it away. Unfortunately, the natural drainage is poor and the expense of establishing artificial drainage would be great. Unfortunately, too, the liberal use of water would be prevented by the limitations of the supply and the cost of pumping. In view of these facts it seems that the general conclusion can not be avoided that in the most alkaline portion of the central flat irrigation by pumping from wells is not feasible, and it becomes necessary to advise against expenditures for pumping plants within this area. A caution should also be given for a wider region having poor drainage, water of intermediate chlorine content, or soil that shows alkali symptoms, lest in the course of time the sparing application of water pumped from wells will result in an injurious accumulation of alkali.

SUMMARY.

The conclusions in regard to irrigation with ground water can be briefly summarized as follows:

In spite of the high cost of fuel, if the water is lifted in the most economical manner and is wisely used, pumping for irrigation can under favorable conditions be made profitable. The underground supply is not large enough to irrigate more than a small part of the total arable area, but it is sufficient to add greatly to the agricultural product of the valley. Even where the depth to water is great the irrigation of a garden, lawn, and orchard will generally be feasible. In the central area, however, the presence of alkali may seriously impair the quality of the water or may prohibit its use. Taken as a whole, the water of Estancia Valley is a valuable resource that should be developed, but its development should be conducted carefully and with full cognizance of the inherent limitations.

TABLES.

The following table shows the depths to water by townships:

Table of depths to water in Estancia Valley.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
1	.....	9	2	11	.....	a 130
2	.....	15	2	11	.....	a 45
3	.....	22	2	12	.....	a 215
4	SW.	27	2	12	In Cedarvale	a 174
5	NW.	31	2	12	.....	a 206
6	NE.	11	3	9	Approximately located	a 80
7	SW.	15	3	10	Progresso station	35
8	NW.	23	3	10	.....	25
9	NE.	1	4	6	.....	a 45
10	NW.	5	4	7	In the arroyo	16
11	NW.	8	4	7	.....	a 50
12	SW.	8	4	7	.....	a 55
13	NE.	11	4	7	.....	110
14	SW.	34	4	7	Relatively low ground	165
15	SW.	14	4	8	.....	90
16	.....	16	4	8	Approximately located	68
17	NE.	23	4	8	.....	93
18	NE.	24	4	8	.....	63
19	SE.	24	4	8	.....	66
20	NE.	26	4	8	.....	105
21	SW.	3	4	9	.....	21
22	SE.	6	4	9	.....	40
23	NE.	7	4	9	.....	42
24	NW.	8	4	9	.....	35
25	NE.	8	4	9	Northwest corner	35
26	NE.	9	4	9	.....do	25
27	NW.	11	4	9	.....	8
28	NW.	31	4	9	.....	a 85
29	SW.	3	4	10	North margin	30
30	NE.	9	4	10	Southeast corner	43
31	.....	3	5	6	In the arroyo	a 80
32	NE.	25	5	6	.....	98
33	SE.	25	5	6	.....	46
34	.....	5	5	7	.....	a 158
35	NE.	13	5	7	.....	51
36	SE.	17	5	7	.....	a 93
37	NW.	21	5	7	.....	a 80
38	NW.	24	5	7	.....	47
39	.....	25	5	7	West margin	13
40	SW.	28	5	7	In the arroyo	a 26
41	SW.	28	5	7	.....	28
42	SW.	28	5	7	.....	38
43	.....	30	5	7	East margin	42
44	SW.	31	5	7	.....	40
45	NW.	33	5	7	.....	a 28
46	SW.	33	5	7	In the arroyo	a 80
47	NE.	1	5	8	.....	22
48	NE.	2	5	8	.....	4
49	SW.	5	5	8	.....	47
50	SW.	6	5	8	Northwest corner	82
51	SE.	8	5	8	.....	50
52	SW.	8	5	8	Northwest corner	47
53	.....	9	5	8	North margin	a 36
54	SE.	9	5	8	On the hill	50
55	NE.	10	5	8	.....	5
56	NW.	11	5	8	.....	a 3
57	SW.	13	5	8	Southeast corner	32
58	SW.	13	5	8	.....	21
59	SW.	14	5	8	.....	14
60	SE.	15	5	8	.....	15
61	SW.	15	5	8	.....	18
62	NW.	18	5	8	Southwest corner	35
63	SE.	21	5	8	.....	23
64	NE.	24	5	8	.....	30
65	SE.	25	5	8	.....	30
66	SE.	31	5	8	.....	76
67	SW.	33	5	8	.....	a 110
68	NE.	35	5	8	.....	31
69	NW.	5	5	9	.....	20
70	NE.	18	5	9	.....	24
71	NW.	19	5	9	.....	26

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
72	SE.	10	5	10		20
73	NE.	13	5	10		*a* 66
74	SE.	13	5	10		*a* 95
75	SW.	4	5	11		56
76	SE.	6	5	11		39
77	.....	8	5	11	West margin	40
78	.....	8	5	11	North margin	40
79	SE.	1	6	7		140
80	.....	5	6	7		*a* 110
81	NE.	14	6	7		170
82	SE.	14	6	7		*a* 165
83	.....	17	6	7	East margin, in the arroyo	90
84	SE.	23	6	7	In the arroyo	75
85	SW.	34	6	7	.....do	*a* 100
86	SW.	35	6	7	.....do	*a* 90
87	SW.	36	6	7	On the upland	102
88	NW.	1	6	8		*a* 26
89	NE.	2	6	8		*a* 18
90	SW.	2	6	8		*a* 8
91	SW.	2	6	8		16
92	NW.	3	6	8		70
93	SW.	3	6	8		16
94	NE.	9	6	8		65
95	SE.	9	6	8		55
96	NW.	10	6	8		45
97	SW.	10	6	8		40
98	SW.	11	6	8		13
99	NE.	12	6	8		18
100	SW.	12	6	8		12
101	NW.	18	6	8		110
102	SE.	19	6	8		*a* 110
103	SW.	19	6	8	Level upland	115
104	NE.	20	6	8		*a* 85
105	SE.	20	6	8		70
106	NW.	21	6	8		*a* 85
107	SW.	21	6	8		*a* 50
108	SW.	22	6	8		28
109	SE.	23	6	8		14
110	NE.	28	6	8		33
111	NE.	26	6	8		6
112	NE.	31	6	8	In the arroyo	35
113	SW.	33	6	8		7
114	SE.	34	6	8	Southwest corner	6
115	NE.	35	6	8		10
116	NW.	35	6	8		*a* 6
117	SW.	1	6	9		*a* 10
118	SE.	3	6	9		*a* 8
119	SW.	5	6	9	Northwest corner	13
120	SW.	5	6	9		14
121	.....	6	6	9	West margin	18
122	.....	7	6	9	North margin	12
123	SW.	10	6	9	Northwest corner	*a* 7
124	NW.	11	6	9		12
125	SE.	11	6	9		*a* 5
126	NE.	12	6	9		20
127	SE.	15	6	9		*a* 6
128	SW.	15	6	9		*a* 5
129	SW.	17	6	9		15
130	SW.	18	6	9	Northwest corner	12
131	NW.	19	6	9		*a* 8
132	SW.	20	6	9		17
133	NW.	29	6	9		18
134	SW.	29	6	9		18
135	.....	26	6	10	Approximately located	36
136	.....	4	6	10	.....do	47
137	SE.	31	6	11		*a* 50
138	.....	15	7	7	East margin, in the arroyo	138
139	SE.	36	7	7		135
140	NW.	1	7	8		30
141	SE.	2	7	8		15
142	NW.	3	7	8		48
143	NW.	4	7	8		*a* 75
144	NW.	6	7	8		*a* 94
145	SW.	7	7	8	In the arroyo	*a* 45
146	.....	10	7	8	East margin	14
147	SW.	12	7	8		33
148	SW.	13	7	8		35
149	SW.	14	7	8		16

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
150	NE.	15	7	8		57
151	SW.	19	7	8	Upland	94
152	SE.	21	7	8		44
153	NW.	26	7	8		14
154	SW.	36	7	8		12
155	NW.	4	7	9		a 25
156	SW.	4	7	9		a 16
157	SW.	9	7	9		a 18
158	SE.	9	7	9		a 14
159	SW.	15	7	9		a 16
160	SW.	16	7	9		a 10
161	SE.	19	7	9		10
162	SE.	20	7	9	South margin	10
163	SE.	21	7	9	do	a 12
164	NW.	22	7	9		a 16
165	SW.	27	7	9		a 8
166	NW.	28	7	9		10
167	SE.	30	7	9		10
168	NW.	34	7	9		a 12
169	SW.	35	7	9		a 12
170	NE.	8	7	10		a 56
171	SW.	8	7	10		a 50
172	.....	9	7	10	South margin	a 70
173	SW.	15	7	10		66
174	NE.	16	7	10		70
175	.....	22	7	10	North margin	a 70
176	.....	31	7	11		a 45
177	SE.	36	8	7		a 85
178	NW.	1	8	8	In the arroyo	16
179	SE.	11	8	8		38
180	NW.	12	8	8		38
181	NE.	14	8	8		28
182	SE.	22	8	8		68
183	NE.	23	8	8	Southeast corner	a 18
184	NE.	23	8	8	Near base of cliff	a 9
185	SW.	24	8	8		19
186	SE.	27	8	8		54
187	NE.	33	8	8		70
188	NW.	8	8	9	Northeast corner	25
189	NE.	17	8	9	Southeast corner	24
190	NW.	28	8	9		22
191	NW.	28	8	9	Southwest corner	20
192	SW.	32	8	9		a 25
193	SW.	33	8	9		20
194	NE.	7	8	10		184
195	NE.	10	9	8		57
196	NW.	14	9	8	Level upland	59
197	NE.	17	9	8	In the arroyo	34
198	NE.	22	9	8	do	a 21
199	NE.	23	9	8		45
200	NE.	24	9	8		36
201	SE.	27	9	8		55
202	NE.	28	9	8		a 83
203	NE.	29	9	8		a 138
204	NE.	31	9	8		a 58
205	NW.	31	9	8		a 98
206	NW.	32	9	8		a 78
207	NE.	32	9	8		a 114
208	NW.	33	9	8		a 100
209	NE.	33	9	8		a 130
210	NE.	35	9	8		27
211	SE.	36	9	8	In the arroyo	30
212	NW.	1	9	9	Southeast corner	63
213	SE.	4	9	9	Southwest corner	26
214	NE.	9	9	9		34
215	SE.	9	9	9		24
216	.....	11	9	9	Center of section	a 25
217	NW.	11	9	9		a 22
218	NW.	12	9	9		a 43
219	SW.	15	9	9		27
220	SW.	17	9	9		24
221	NW.	19	9	9		26
222	NE.	20	9	9		15
223	SW.	29	9	9		16
224	SE.	30	9	9		18
225	SW.	5	9	10		129
226	NE.	1	10	8		88
227	NW.	2	10	8		135

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Table of depths to water in Estancia Valley—Continued.

No.	Quarter of section.	Section.	Township north.	Range east.	Situation of well.	Depth to water.
						Feet.
228	SW.	2	10	8		a 148
229	SW.	4	10	8	In the arroyo	159
230	S.	8	10	8		a 174
231	SE.	9	10	8		a 110
232	NW.	11	10	8		a 135
233	NW.	14	10	8		a 115
234	SE.	14	10	8		a 80
235	NE.	15	10	8		a 85
236	SE.	15	10	8	Upland	a 97
237	NE.	17	10	8		a 165
238	NW.	21	10	8		a 141
239	NW.	21	10	8	Southwest corner	127
240	NW.	22	10	8	In the arroyo	a 100
241	SW.	22	10	8	Upland	a 112
242	NE.	23	10	8		a 80
243	NW.	24	10	8		a 80
244	SE.	27	10	8	In the arroyo	55
245	NE.	34	10	8	Upland	74
246	SW.	34	10	8		a 165
247	NE.	35	10	8		a 44
248	SW.	1	10	9		a 105
249	NW.	3	10	9		99
250	SE.	4	10	9		a 66
251	SE.	4	10	9	Northeast corner	a 82
252	NE.	5	10	9		78
253	NW.	5	10	9		75
254	SW.	5	10	9	Northwest corner; in arroyo	a 60
255		6	10	9	North margin	72
256	SE.	6	10	9		62
257	SE.	9	10	9	Northeast corner	75
258	SW.	17	10	9	Southeast corner	a 42
259		18	10	9	East margin	51
260	NE.	19	10	9		42
261	SW.	26	10	9	Northwest corner	35
262	SW.	27	10	9		27
263	NW.	29	10	9		45
264	NW.	34	10	9	In the arroyo	a 20
265	SW.	34	10	9		a 15
266	SW.	35	10	9	Northwest corner	a 15
267	SE.	35	10	9	Northeast corner	25
268	NE.	5	10	10		a 165
269	SW.	1	11	8	In the arroyo	a 200
270		22	11	8	South margin	a 135
271	SW.	24	11	8		a 110
272	SE.	28	11	8	Upland	a 184
273	SE.	8	11	9		144
274	NE.	18	11	9	Southeast corner, depth of well 139 feet	
275		19	11	9	South margin	a 90
276	SE.	20	11	9	In the arroyo	a 110
277	NW.	28	11	9		147
278	SE.	28	11	9	In Stanley	152
279		31	11	9	North margin; slightly above the arroyo	82
280	NE.	28	11	9		a 107
281	SE.	30	11	10		a 213
282		32	11	10	Near center of section	a 175

a Depth not measured, but given on the authority of owner, driller, or other responsible person.

Field assays of water in Estancia Valley.

[Quantities in parts per million.]

No.	Owner.	Location.	Description of well.	Depth of well.	Depth to water.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[a]	Chlorine (Cl).
				Feet.	*Feet.*				
1	Cedarvale well	SW. ¼ sec. 27, T. 2 N., R. 12 E	Drilled, partly cased	298	174	0	424	>625	55
2	Mountainair village well	Mountainair	Drilled	303		0	212	157	9
3	Elijah Bradley	NE. ¼ sec. 11, T. 3 N., R. 9 E	do	100	80	0	170	>625	25
4	Progresso well	SW. ¼ sec. 15, T. 3 N., R. 10 E	Dug		35	0	158	574	33
5	J. S. Penny	NE. ¼ sec. 1, T. 4 N., R. 6 E	do	50	45	0	206	<30	13
6	S. R. Seymour	SW. ¼ sec. 8, T. 4 N., R. 7 E	Drilled	110	55	0	170	<30	17
7		NE. ¼ sec. 11, T. 4 N., R. 7 E	do	150	110	0	218	<30	13
8	J. B. Vincent	NE. ¼ sec. 23, T. 4 N., R. 8 E		95	93	0	194	160	24
9	E. P. Parker	NE. ¼ sec. 24, T. 4 N., R. 8 E	Dug		63	0	146	146	20
10		SE. ¼ sec. 24, T. 4 N., R. 8 E	do		66	0	158	181	18
11	W. R. Walden	NE. ¼ sec. 26, T. 4 N., R. 8 E	do	120	105	0	158	181	18
12	Ranch	NE. ¼ sec. 32,[b] T. 4 N., R. 8 E				0	121	>625	25
13	Eugene Forbes	SE. ¼ sec. 6, T. 4 N., R. 9 E	Dug	40	40	0	194	197	31
14	Atchison, Topeka & Santa Fe Ry. wells at Willard.	NW. ¼ sec. 8, T. 4 N., R. 9 E				0	218	238	46
15		NW. ¼ sec. 11, T. 4 N., R. 9 E	Dug		8	0	291	>625	417
16	A. P. Hanna	NW. ¼ sec. 31, T. 4 N., R. 9 E	do	98	85	0	109	>625	17
17	Ranch	SW. ¼ sec. 3, T. 4 N., R. 10 E	do		30	0	412	>625	1,165
18	do	Sec. 33,[b] T. 4 N., R. 10 E				0	133	383	40
19	J. B. Teague	SE. ¼ sec. 17, T. 5 N., R. 7 E		115	93	0	230	<30	9
20	Ranch	SW. ¼ sec. 33, T. 5 N., R. 7 E	Dug		15	0	327	35	17
21	L. Knight	NE. ¼ sec. 1, T. 5 N., R. 8 E	Large dug hole	27	20	0	243	80	15
22	Thomas Elgin	SW. ¼ sec. 6, T. 5 N., R. 8 E	Dug		82	0	182	<30	7
23		NE. ¼ sec. 35, T. 5 N., R. 8 E	do		31	0	267	42	15
24		NE. ¼ sec. 18, T. 5 N., R. 9 E	6-inch, with casing	36	24	0	545	478	65
25	E. L. Moulton	SE. ¼ sec. 13, T. 5 N., R. 10 E	Drilled and cased	120	95	0	121	>625	141
26	Fletcher Brown	SW. ¼ sec. 4, T. 5 N., R. 11 E	do	84	65	0	340	406	261
27	Stream	Sec. 26,[b] T. 6 N., R. 6 E					158	<30	10
28	Spring in foothills	Sec. 34,[b] T. 6 N., R. 6 E				0	388	<30	7
29	Porter ranch	SW. ¼ sec. 34, T. 6 N., R. 7 E		125	100	0	218	<30	7
30	L. C. Weaver	NW. ¼ sec. 1, T. 6 N., R. 8 E	Not cased	40	26	0	679	328	140
31	R. B. Cochran	SW. ¼ sec. 11, T. 6 N., R. 8 E	Dug		13	0	267	<30	35
32	Estancia Spring	SE. ¼ sec. 11, T. 6 N., R. 8 E				0	291	<30	17
33	Box factory, Estancia	NW. ¼ sec. 12, T. 6 N., R. 8 E	Cased to 59 feet		20	0	873	>625	251
34	W. J. Adair	NW. ¼ sec. 12, T. 6 N., R. 8 E	Dug		18	0	631	574	693
35	Valley Hotel, Estancia	SW. ¼ sec. 12, T. 6 N., R. 8 E				0	320	383	54

[a] >=more than; <=less than.

[b] Approximate location.

Field assays of water in Estancia Valley—Continued.

No.	Owner.	Location.	Description of well.	Depth of well.	Depth of water.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).[a]	Chlorine (Cl).[a]
				Feet.	*Feet.*				
36	N. E. Bilsing	SE. ¼ sec. 13, T. 6 N., R. 8 E.		12	9	0	243	344	84
37	H. C. Williams	NE. ¼ sec. 26, T. 6 N., R. 8 E.	Dug		6	0	243	50	20
38	do	NE. ¼ sec. 26, T. 6 N., R. 8 E.	Drilled and cased	318	4	0	533	66	139
b39	H. N. Summers	SW. ¼ sec. 1, T. 6 N., R. 9 E.	3-inch casing to 45 feet	65	10	0	243	431	438
b40	do	SW. ¼ sec. 1, T. 6 N., R. 9 E.	do	65	10	0	243	553	393
41	N. Williams	SE. ¼ sec. 3, T. 6 N., R. 9 E.	Cased	26	9	0	364	>625	914
42	T. J. Moore	SW. ¼ sec. 5, T. 6 N., R. 9 E.	Dug		13	0	340	383	80
43	Mrs. N. L. Williams	NE. ¼ sec. 10, T. 6 N., R. 9 E.	Cased	32	7	0	303	>625	15,075
44	Unsuccessful test well	SW. ¼ sec. 10, T. 6 N., R. 9 E.	Cased to 205 feet	215	7	0	533	553	784
45	A. Abbott	SE. ¼ sec. 11, T. 6 N., R. 9 E.	Cased to 100 feet	159	5	0	243	328	309
46	Charles May	NE. ¼ sec. 12, T. 6 N., R. 9 E.	Dug	20	20	0	259	>625	16,442
47	A. Abbott	SE. ¼ sec. 15, T. 6 N., R. 9 E.	Cased to 120 feet	156	6	0	424	553	603
48	do	SW. ¼ sec. 15, T. 6 N., R. 9 E.	do	156	5	0	582	553	932
49	J. J. Smith	NW. ¼ sec. 19, T. 6 N., R. 9 E.	Drilled, 6-inch casing	60	8	0	315	91	40
50	W. H. Hancock	NE. ¼ sec. 20, T. 6 N., R. 9 E.	Drilled and cased	90		0	679	>625	603
51	C. B. Cornell	SW. ¼ sec. 28, T. 6 N., R. 9 E.	Not cased	18	14	0	728	>625	269
52	A. L. Bilsing	N. ½ sec. 33, T. 6 N., R. 9 E.	Drilled and cased	100	14	0	752	>625	587
53	Wm. Dunbar	Sec. 4,[c] T. 6 N., R. 10 E.		50	47	0	194	553	283
54		Sec. 26,[c] T. 6 N., R. 10 E.	Dug		36	0	218	>625	2,412
55	E. F. Heal	SE. ¼ sec. 31, T. 6 N., R. 11 E.	do	60	50	0	194	492	361
56	J. B. Gwaltney	SE. ¼ sec. 36, T. 7 N., R. 7 E.	Drilled	139	135	0	170	<30	13
57	Antelope Spring	SW. ¼ sec. 14, T. 7 N., R. 8 E.				0	364	<30	20
58	M. Freilinger	SW. ¼ sec. 24, T. 7 N., R. 8 E.	Dug		35	0	340	42	55
59	J. B. Striplin	SE. ¼ sec. 20, T. 7 N., R. 9 E.	do		10	0	267	265	219
60	B. W. Honnold	SE. ¼ sec. 21, T. 7 N., R. 9 E.	Drilled and cased	140	12	0	243	383	234
61	J. W. Kooken	NW. ¼ sec. 28, T. 7 N., R. 9 E.	Not cased		10	0	680	>625	5,276
62	T. J. Curtis	SE. ¼ sec. 30, T. 7 N., R. 9 E.	Dug		10	0	352	287	85
63	Duncan McGillivray	NE. ¼ sec. 8, T. 7 N., R. 10 E.	Drilled	93	56	0	133	150	40
64	E. F. Moore	SW. ¼ sec. 15, T. 7 N., R. 10 E.			66	0	170	256	65
65	Allan McGillivray	Sec. 31, T. 7 N., R. 11 E.	Drilled	120	45	0	97	>625	60
66	S. E. Keehnel	SE. ¼ sec. 36, T. 8 N., R. 7 E.		140	85	0	279	30	25
67		NW. ¼ sec. 1, T. 7 N., R. 8 E.	6-inch, not cased		30	0	315	43	25
68	John T. Lee	NW. ¼ sec. 28, T. 8 N., R. 9 E.	Not cased	25	22	0	218	460	319
69	J. O. Justus	SW. ¼ sec. 33, T. 8 N., R. 9 E.	do	25	20	0	291	>625	2,010
70	Ranch	SE. ¼ sec. 8,[c] T. 9 N., R. 8 E.			34	0	194	<30	10
71	Michael T. Moriarty	NE. ¼ sec. 22, T. 9 N., R. 8 E.	Dug	32	21	0	218	82	301
72	W. C. Maurer	NW. ¼ sec. 1, T. 9 N., R. 9 E.	Drilled	70	63	0	158	460	274
73	Robert Hickman	SE. ¼ sec. 4, T. 9 N., R. 9 E.	Not cased	30	26	0	170	460	251
74	Edith B. Rush	SW. ¼ sec. 29, T. 9 N., R. 9 E.	Dug		16	0	206	574	222

75	B. Hill	NW. ¼ sec. 28, T. 9 N., R. 10 E.	Drilled	189		0	194	197	20
76	A. Stewart	NW. ¼ sec. 21, T. 10 N., R. 8 E.	do		127	0	206	<30	10
77	R. H. Harper	NE. ¼ sec. 34, T. 10 N., R. 8 E.	do	100	74	0	194	34	15
78	S. F. Kelly	NW. ¼ sec. 3, T. 10 N., R. 9 E.	do		99	0	194	61	13
79	John H. Cantwell	NW. ¼ sec. 5, T. 10 N., R. 9 E.	do	103	75	0	170	95	13
80	E. H. Clayworth	SW. ¼ sec. 27, T. 10 N., R. 9 E.	Dug		27	0	146	383	119
81	G. W. Hearte	NE. ¼ sec. 5, T. 10 N., R. 10 E.		180	165	0	243	56	14
82	Deserted ranch	SW. ¼ sec. 1, T. 11 N., R. 8 E.	Dug	250	200	0	182	78	8
83	Stanley village well	Stanley		160	152	0	230	52	13
84	W. C. Asher	do	Drilled	207	100	0	243	94	18

[a] >=more than; <=less than. [b] Samples 39 and 40 were taken from the same well, but at different times and after different rates of pumping. [c] Approximate location.

Tests made by the Atchison, Topeka & Santa Fe Railway Co. of water from its wells in Estancia Valley, N. Mex.

[Reported by the railway company in grains per United States gallon but recalculated, for convenience in comparison, to parts per million.]

No.	Location.	Depth of well.	Depth to water.	Depth from which water was taken.	Incrustants, including silica and iron, and carbonates, sulphates, and chlorides of calcium and magnesium.	Foaming material (including organic matter and carbonates, sulphates, and chlorides of sodium and potassium).	Total solids.
		Feet.	*Feet.*	*Feet.*			
1	Mountainair	330	210	283	1,038	171	1,209
2	do	330	210	295	516	85	601
3	do	330	210	.....	246	.....	410
4	do	330	210	300	210	50	260
5	Willard	440	35	41	340	111	451
6	do	440	35	41	337	299	636
7	do	440	35	52	404	123	527
8	do	440	35	52	395	128	523
9	do	440	35	130	325	92	417
10	do	440	35	146	320	108	428
11	do	440	35	223	369	116	485
12	do	440	35	233	364	135	499
13	do	440	35	.....	304	.....	412
14	do	440	35	.....	340	92	432
15	do	440	35	.....	556	121	677
16	do	440	35	.....	400	207	607
17	Lucia	350	40	120	2,724	429	3,153
18	do	350	40	315	2,348	198	2,546
19	do	350	40	350	2,139	216	2,355

NOTE ON GEOGRAPHIC NAMES.

Estancia Valley has occasionally been called "Sandoval Basin" or "Sandoval Bolson" after the large Antonio Sandoval land grant which it once contained, but the name "Estancia Valley" is now in general use.

For generations the Mexican inhabitants have had definite names for the principal mountains, buttes, arroyos, salt basins, and other topographic features, but the American settlers who have recently come into the valley show a tendency to ignore these Spanish names. Frequently the English translation of the Spanish name is used, but in some cases entirely new names are applied or no name at all is known. In this paper the Spanish names are consistently retained because they have the sanction of long usage and are more distinctive and euphonious than the English names of recent origin. Below are given some translations and alternative names:

Arroyo Fecundo	Fertile Draw.	Laguna Chica	Little Lake.
Arroyo del Cibolo	Buffalo Draw.	Punta de Agua	Point of water.
Arroyo del Sinsonte	Mocking Bird Draw.	Manzano (range)	Apple-tree (range).
Arroyo Mesteño	Ranchers' Draw.	El Cuervo (butte)	Crow (butte).
Cañada Colorado	Red Canyon.	Cerrito del Lobo	Wolf Hill.
Laguna del Perro	Dog Lake.	Pedernal (mountain)	Flint (mountain).
Laguna Salina	Salt Lake.		

Arroyo Mesteño is well known as Manzano Draw, and Arroyo de Ortiz as Moriarty Draw.

GROUND-WATER CONDITIONS IN PARTS OF CENTRAL NEW MEXICO.

A RECONNAISSANCE IN ENCINO BASIN, NEW MEXICO.

LOCATION AND AREA.

Encino Basin lies in the central part of New Mexico, immediately east of Estancia Basin (fig. 1). Like the latter, it forms a closed depression whose drainage channels lead to a low central flat, but it is much smaller than Estancia Basin, its area being not much more than one-tenth as great. It is bordered on the north by the drainage basin of Cañada Pintada, which leads to Pecos River, on the east by a gently undulating upland that is drained eastward, and on the south by a closed depression known as Pinos Wells Basin and by a very small closed basin that intervenes between Encino and Pinos Wells basins.

PHYSIOGRAPHY AND GEOLOGY.

UPLAND AREAS.

The borders of Encino Basin are in general much lower than those of Estancia Basin, and at no place do they assume the character of mountain ranges. Most of its area consists of gently undulating, grass-covered upland that lies west and northwest of the low flat and is traversed by arroyos that drain the storm waters toward this flat, the divides which separate the upland from Estancia Basin and Cañada Pintada being inconspicuous. The divides on the south and east are relatively near the flat and are still lower and less conspicuous. On the northeast the basin is bordered by a low mesa that supports some trees.

The western upland is underlain largely by granite with associated schist and quartzite, but a series of stratified formations, probably continuous with some of the Carboniferous formations found in Estancia Basin, also appears. In the railway excavation west of Negra, there is an exposure of gray, chocolate, and greenish shales and an overlying pink conglomerate, derived chiefly from granite. The conglomerate rests upon the shale with pronounced unconformity. It outcrops at other points and has been encountered in some of the wells near Negra. Limestone is exposed a short distance east of this station, and sandstone and other rocks

appear in the divide on the east side of the basin. West and south of the flat south of Encino there is a conspicuous cliff, several miles in total length, in which red beds containing thick layers of gypsum come to the surface. In general the stratified beds are horizontal or have only gentle dips, but at some points displacements and abrupt changes in dip are found. Beds underlain by gypsum are likely to be more or less disturbed by caving that results from the removal of the gypsum through its solution in percolating waters.

ANCIENT LAKE BED.

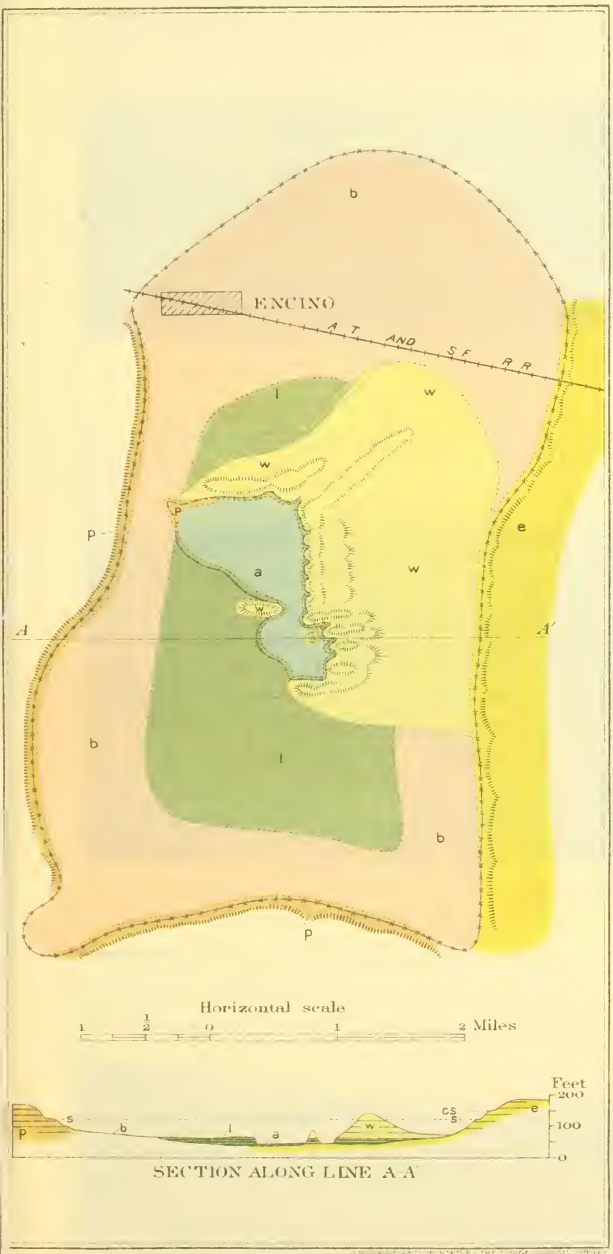
Although this basin is so much smaller than Estancia Basin and has no mountain ranges to supply water, there is indisputable evidence that its lowest part was at one time occupied by a lake (Pls. XII and XIII). As in Estancia Basin, this evidence is furnished by the delicately laminated sedimentary beds, such as are deposited only at the bottom of a body of standing water, by a flat plain characteristic of the bed of a desiccated lake, and by terraces, beaches, and other markings, whose occurrence at certain levels indicate ancient strands or shore lines.

LAKE SEDIMENTS.

In the village of Encino exposures afforded by cellars and dug wells show irregular beds of sand, gravel, and clay, but no beds that resemble the laminated lake sediments in Estancia Valley. The same is true of wells and cellars east and southeast of the village, in the vicinity of the railroad; but less than a mile south and a short distance east of Encino, on slightly lower ground, a dug well was found in which about 4 feet of typically laminated lake beds occur. They rest on nonlaminated yellow sand and gravel and are overlain by about 2½ feet of dark soil with some pebbles at the surface.

About a mile farther south there is a salt basin similar to those in Estancia Valley (Pl. XIV, *A*). At the north margin of this basin lake sediments are only imperfectly developed, while beds of gypsum and other old formations make up the floor and the lowest parts of the sides of the basin. The floor is strewn with pebbles, which have evidently been washed thus far by water but which could not be removed by the wind when it excavated the basin.

In the southeastern part of the basin the conditions are entirely different. Here more than 20 feet of typical lake sediments outcrop (Pl XIV, *B*). They contain some sand and gypsum but consist chiefly of laminæ of clay. The perfect stratification and fineness of the material is remarkable when the small size of the ancient lake is considered. Near the bottom there are calcareous beds, the heaviest of which has a thickness of more than half an inch. At a few places a nonlaminated formation appears below the lake sediments, thus



LEGEND

a

Recently deposited clay with precipitates of salts left by evaporating waters

w

Post-lacustrine wind deposits, consisting of clay with minor amounts of sand and gypsum

b

Beach material, alluvium, etc., found in the littoral zone of the ancient lake bed

l

Finely stratified lake sediments, consisting of clay with minor amounts of sand and gypsum

e

Pre-lacustrine wind deposits, consisting of clay with minor amounts of sand and gypsum (In part reworked by the wind in recent times and mantled with post-lacustrine wind deposits)

p

Gypsum and red beds, probably Pennsylvanian

Outline of salt basin

Outline of ancient lake bed

s

Principal strand of ancient lake

cs

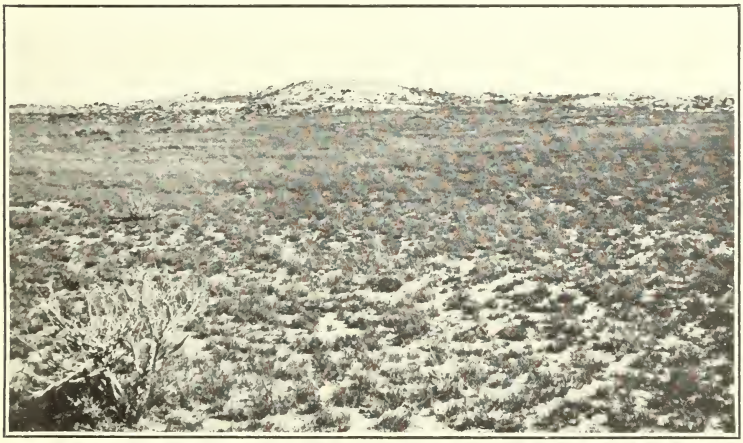
Conjectured highest strand of ancient lake

(All boundaries are approximate)

RECONNAISSANCE GEOLOGIC MAP OF THE ANCIENT LAKE BED IN THE ENCINO BASIN, NEW MEXICO

A. TERRACE ON EAST SIDE OF ANCIENT LAKE BED NEAR ENCINO.

See page 77.



B. TERRACE ON SOUTH SIDE OF ANCIENT LAKE BED NEAR ENCINO.

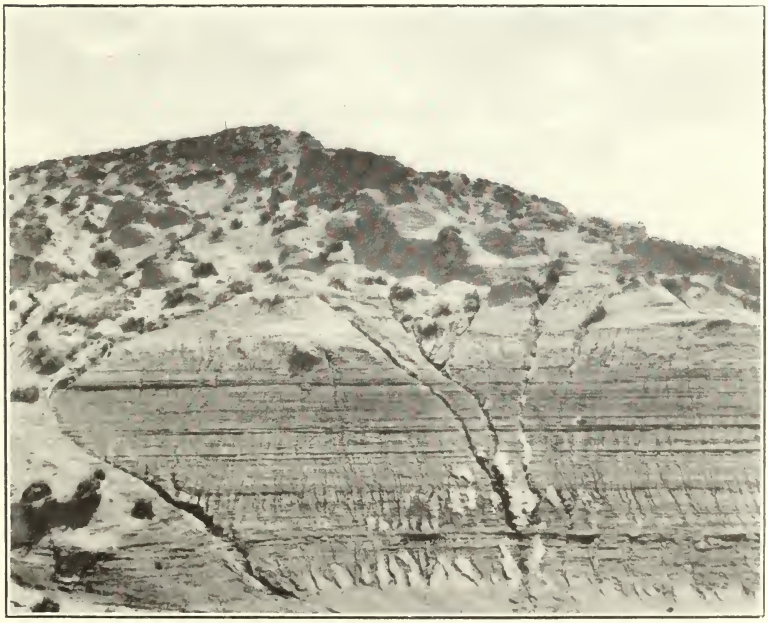
See page 77.

C. GAP IN ANCIENT BEACH BAR NEAR ALLEN McGILLIVRAY RANCH.

See page 20.

A. ENCINO SALT BASIN.

See page 78.



B. STRATIFIED LAKE SEDIMENTS IN ENCINO SALT BASIN.

See page 76.

showing that the entire lake series is exposed. No pebbles are found on the floor of this part of the salt basin.

The exact extent of the lake sediments is not known, but they appear to be present in the materials thrown up from wells sunk at different points on the flat south of the basin. They probably extend beneath the low flat part of the ancient lake bed and are absent where the surface rises perceptibly. Their presence at the surface is probably indicated by the abundance of the large brush, *Atriplex canescens* (?).

SHORE FEATURES.

As nearly as was ascertained, the area of the ancient lake was about 18 square miles, or only one-twenty-fifth of the area of Lake Estancia. Since the size of shore features depends largely upon the size of the waves, and the latter depends largely upon the size of the lake and consequent sweep of the wind, it might be expected that the shore line of Lake Encino would be very feebly marked. It is therefore rather surprising to find that some of the features rival in size those in Estancia Valley but that they are generally less distinct and less well preserved.

The principal shore features in this basin consist of cliffs and attendant cut and built terraces. These are found on the steep west, south, and east sides, where conditions were favorable for this kind of wave work.

On the west and south sides the cliffs and terraces are for the most part cut into the soft red beds, which yield readily to wave work, and into somewhat harder layers of gypsum (Pl. XIII, *B*). Since the caving produced by the gypsum causes small gentle synclines and anticlines, the lake terrace is repeatedly interrupted and is therefore rather disappointing in its general appearance; but the fact that it retains its horizontality and intersects the dipping strata greatly strengthens the evidence that it is a true ancient strand.

On the east side the shore line was for the most part imposed upon wind-deposited clay (Pl. XIII, *A*). The character of this material is such that it must have yielded very freely to wave work, and hence it is not surprising that the lake terraces should here be large. The character of the material also affords the explanation for their poor preservation. While on the Estancia lake bed running water has accomplished but little destructive work, post-lacustrine wind erosion has been notably effective, and the shore features are well preserved because they are generally gravelly and hence not susceptible to wind erosion. Examination shows that the partial destruction of the lake terrace on the east side of Lake Encino is mainly the work of the wind and to only a small extent of the streams. When one observes the great amount of wind work that has been accomplished since the drying up of the lake in the excavation of the salt basin

and takes note of the present erosive activity of the wind, the poor state of preservation of the terraces is no longer puzzling.

While the lake in Encino Basin was very much less extensive than that in Estancia Basin, it did not compare so unfavorably in depth. The shore line referred to in the foregoing description is the only distinct and certain one. As nearly as could be estimated it stands about 60 feet above the lowest part of the lake flat. No shore features were observed at lower levels, but there is some evidence (which need not be discussed here) that the water stood temporarily at a higher level. If this is true, the lake history of this basin would appear to be correlated with that in Estancia Basin, inasmuch as a temporary high-water stage is postulated for both lakes.

SALT BASIN AND POST-LACUSTRINE WIND DEPOSITS.

The lake flat contains a single large salt basin, which is of the same type as the salt basins on the flat of Lake Estancia (Pl. XIV, *A*). Like them, it was obviously excavated by the wind to the ground-water level and has a flat bottom and precipitous walls. As in Estancia Valley, the effect of prevailing westerly winds is obvious, the west margin being entirely destitute of wind deposits while the east margin is bordered by ridges and hills, the highest of which reach an altitude of fully 100 feet above the floor of the basin. As in Estancia Valley, the wind deposits form a sharp contrast with the lake sediments, upon which, in some places, they rest with pronounced unconformity. Again, as in Estancia Valley, the clay deposits hug the basin closely, producing a topographic feature that bears a superficial resemblance to a volcano with a large crater. If the material excavated were more granular, like sand, it would be carried farther and would not remain in such close proximity to the salt basin. The sand and gypsum sand present are found chiefly at the tops of the ridges or in the thin blanket of eolian material that is spread over the lake bed to the leeward of the clay hills. The wind is constantly attacking the structures which it has itself thrown up. It gouges out precipitous trenches on the windward side of the clay hills and deposits the material thus acquired in elongated mounds to the leeward (Pl. XII).

In the northern part of the valley the clay hills have a subdued aspect and are covered with grass, indicating that wind work has not been active in recent times, but in the southern section the hills are higher, more fantastically carved, and largely destitute of vegetation on the windward side, showing in every way that the wind is still actively at work. In some places the wind has eroded thin layers of limestone and other indurated deposits.

At the time the basin was visited most of its floor was miry, but only a small part was covered with water. The position of the sub-

merged part is significant. The work of the wind is to a small extent undone by the occasional rains which wash some of the excavated material back upon the floor of the basin, producing miniature alluvial slopes. Since the wash is greatest from the highest clay hills, the lowest depression, where the water stands longest after a rain, is located on the west side of the basin as remote as possible from these hills, just as on a larger scale in Sevier Desert, Utah, the lowest depression, occupied by Sevier Lake, is remote from the lofty mountains that yield the most alluvium.

PRELACUSTRINE WIND DEPOSITS.

The deposit found beneath the lake sediments in the southeastern part of the salt basin consists of a light slate-colored, granular, gypsiferous material in which no stratification was noticeable. At no place was an outcrop more than a few feet thick observed, and the exposures were so poor that its character could not be positively ascertained. Yet its appearance indicates that it is probably a prelacustrine wind deposit in which the yellowish tint was changed to bluish by the deoxidation of the iron present. In the wells that have been sunk on the flat south of the salt basin, the same bluish, granular, gypsiferous material is invariably brought to the surface after the lake sediments have been passed through.

On the east side the depression occupied by the ancient lake bed is bordered by pale yellowish gray clay whose character, as a typical wind deposit, is well shown in the railway cut, where a thickness of more than 20 feet is freshly exposed. The topography is also typical of wind work. On the windward side the deposit has been thrown up to form an almost precipitous escarpment, but on the leeward side it slopes gradually, as shown in the section, Plate XII, and eventually disappears altogether. Its general prelacustrine age is fixed by the lake terrace built upon it.

As has been explained, the depression occupied by the ancient lake is bordered on the west, south, and east by abrupt, cliff-like walls. This depression with its precipitous walls was not formed by the lake itself. It was in existence before the advent of the lake and afforded a basin in which the surplus waters collected and were held within definite and constricted limits, without which perhaps no permanent lake would have been produced. The effect of the lake was merely to fill the lowest parts of the depression sufficiently to produce a central flat and to cut a notch at a certain level into the precipitous walls. The general relations suggest that the depression itself may be, at least in part, the product of prelacustrine wind work.

THE MAP.

The map of the ancient lake bed in the Encino Basin (Pl. XII) is introduced to illustrate the features described. It was sketched without an adequate base and the boundaries are merely approximate.

SOIL.

An investigation of the soil would probably develop the fact that Encino Basin is divisible into four soil provinces—the uplands, where the soil is no doubt generally fertile; the littoral zone of the ancient lake bed (*b* in Pl. (II), where the soil is probably also good but is likely to contain more soluble salts; the lake flat (*l* in Pl. XII), where there is likely to be an objectionable amount of alkali and where the predominant vegetation consists of brush; and the areas covered by wind deposits (*w*, and perhaps also *e*, in Pl. XII), where the soil is probably rich in gypsum but less heavily impregnated with alkali than the soil of the lake flat, and where grass instead of brush is the predominant vegetation.

The following analysis indicates a soil that is not seriously impregnated with alkali, nearly all of its soluble matter being gypsum.

Analysis of soil at Encino, N. Mex.

	Per cent of total soil.
Total soluble solids:	
First foot	0.11
Second foot	1.15
Third foot	1.15
Composite of upper 3 feet:	
Total soluble solids (calculated)	.80
Calcium (Ca)	.21
Magnesium (Mg)	.004
Sulphate (SO_4)	.48
Carbonate (CO_3)	None.
Bicarbonate (HCO_3)	.024
Chlorine (Cl)	.002

The samples were taken near the residence of David Liles, north of the depot. The analyses were made in September, 1910, by F. M. Eaton, Oakland, Cal. The percentages are based on the air-dried soil.

GROUND WATER.

OCCURRENCE AND HEAD.

Wells are found in the ancient lake bed and at numerous points on the uplands. At Encino the water table stands 20 to 25 feet below the surface, and it is said to be at about this depth through the low flat area that extends southward from the village. It no doubt coincides approximately with the floor of the salt basin. On the

uplands the depth to water is, of course, greater, and most of the wells are located in arroyos.

At Negra, which is located in an arroyo west of Encino, the Atchison, Topeka & Santa Fe Railway Co. has sunk several wells and is at present drilling two others. The principal railroad well now in use is 500 feet deep. It has an 8-inch casing extending to a depth of 350 feet and 6-inch casing from 350 feet to the bottom. The well is said to extend through various rock formations. Strainers are inserted at six horizons and difficulty is experienced in keeping out the fine sand. The other well at present in use is 171 feet deep. The normal water level in the wells is said to be about 70 feet below the surface and the pump in the 500-foot well 280 feet below the surface. As a rule both wells are pumped continuously and furnish about 3,400 gallons per hour, about 14 gallons per minute being drawn from the 171-foot well and 42 gallons per minute from the 500-foot well. At the time the station was visited this was the maximum yield of the wells, but it was believed that by cleaning out the sand that had accumulated the supply could be materially increased.

The well of D. J. Bigbee is located in the NW. ¼ sec. 23, T. 7 N., R. 13 E., about 15 miles northwest of Encino. It is in the arroyo of Cañada Pintada, a short distance north of the divide. This well was drilled 230 feet deep, and the water, which was encountered at 226 feet, rose to a level about 185 feet below the surface. It is reported that 5,000 gallons have been pumped from it in 10 hours without noticeable effect. A similar well is located about 1 mile farther south, and several other wells with windmills were observed in the arroyo that leads toward the village of Encino.

The vicinity of Encino is underlain by sand and gravel that will probably yield its water freely. Less certainty exists as to the water-bearing capacity of the underlying deposits farther south, on the lake flat. No gravel or quartz sand was observed in the materials brought out of the wells on the flat south of the salt basin, and in some localities the gypsum and red-beds series is near the surface.

QUALITY.

The water from the upland wells is generally reported to be of good quality. The railroad supply at Negra is said to be preferred to the water at Willard for use in boilers. At Encino the water is highly mineralized that it is avoided for drinking and household use. On the flat farther south it is reported still worse. Numerous dug wells were found on the flat south of the salt basin, but none seemed to be in use. It is likely that the conditions in this basin are analogous to those found in Estancia Basin.

Below is given an assay of the water from the well of H. B. Markham, in the village of Encino. This is a dug well about 25 feet

deep. It penetrates irregularly deposited bodies of clay and gravel and ends in a bed of sand. The water level is 22 feet below the surface. The assay indicates that the water is similar to the gypsiferous water in the Estancia Valley.

Assay of well water at Encino, N. Mex.

[Parts per million.]

Carbonate radicle (CO_3)	0
Bicarbonate radicle (HCO_3)	109
Sulphate radicle (SO_4)[a]	2,300
Chlorine (Cl)	126

IRRIGATION.

The rainfall is not sufficient to assure crops by dry-farming methods, and there are no permanent streams. A remote possibility exists that flowing wells could be obtained, but the indications are less promising than in Estancia Valley, where drilling has developed unfavorable results. There is, however, reason to believe that some land can be successfully irrigated by pumping from wells. In parts of the shallow-water belt detrimental quantities of alkali are likely to be present. Hence, before a pumping plant is installed analysis should be made of the soil that is to be irrigated and of the water that is to be used. The principal water supply is to be expected from the sand and gravel in the valley fill, and, since the average thickness of this fill appears not to be great, the amount of available ground water is probably not large. Pumping plants of moderate size should first be installed, and after these have been successfully operated further developments can be made. The most promising field for irrigation is not on the low flat, where alkali conditions are likely to be encountered, nor on the elevated uplands, where the depth to water is great and the supply is generally small, but on intermediate ground, where the soil is not strongly impregnated with alkali and where water of fairly good quality occurs at moderate depths in the porous materials of the valley fill. However, the fact that irrigation of small plats is feasible even where the water is far below the surface is shown on D. J. Bigbee's ranch, where an abundant yield of vegetables for home use was raised by irrigating with water lifted by a windmill from a depth of nearly 200 feet.

RECONNAISSANCE IN PINOS WELLS BASIN, N. MEX.

PHYSIOGRAPHY AND GEOLOGY.

Pinos Wells Basin lies east of Estancia Basin and south of Encino Basin (fig. 1), and is comparable in size to the latter. Like the others, it has no drainage outlet, the waters of its occasional storms flowing from the relatively high tracts near its margin toward the

[a] Turbidimeter method, by dilution.

lower ground in the interior. In the low central part there are two large salt basins which bear some resemblance to those on the Estancia and Encino flats. They have been produced in the same way by westerly winds, which have eroded to the ground-water level and deposited their loads on the eastern or leeward sides. The peculiar susceptibility of the clay in these three basins to yield to wind erosion is perhaps to be found in its gypsiferous character.

With these general resemblances, however, the parallelism between this basin and the other two ends. No ancient shore features were found, although search was made for them at all levels. Tracts of relatively smooth lowlands adjoin the salt basin on the west, but they lack the distinctive flatness that characterizes the ancient lake beds. No cliff-like walls such as are formed by the laminated lake sediments surround the salt basin. Sediments of this character are lacking, though at a few points south of the west basin stratified beds bearing some resemblance to the laminated lake sediments were observed. The deposits underlying the lowlands in the vicinity of the salt basins are of various kinds, among which are found gravel and pebbly clay. A pavement of pebbles like that found at the north end of the Encino salt basin is spread over the floors of the salt basins in many localities. Such a pavement is not found where lake sediments alone have been eroded. In some places these residual pebbles have accumulated to such an extent as to prevent further wind erosion, thus forming miniature monadnocks on the eolian peneplain.

The wind deposits are different from those in the other two basins. They consist more largely of gypsum, and in some places constitute an almost pure gypsum sand. The gypsum sand is more granular than clay and drifts more readily with the wind; hence a somewhat different wind topography has resulted. The deposits do not hug the salt basins so closely and do not produce so much of the crater effect. They have been carried farther from the salt basins and cover a larger area, forming mounds and hills that more nearly resemble ordinary sand dunes, although they differ from these in being more irregular and fantastic. Gypsum sand also differs from clay in its character as a soil. It supports a scattered growth of small pines, which are not found on the clay hills, and appears to produce a better growth of grass in some places.

GROUND WATER.

Wells are numerous in the dune area and on the low tracts that surround the salt basins. Near the basins are dug wells filled to the brim with water. Some of these wells are pumped by windmills and afford supplies for sheep and other live stock, but the water is so highly mineralized that it is not used for drinking or for culinary purposes. West of the west basin and at a somewhat higher level

there are springs which yield better water. All the inhabitants of the region are said to haul their household supplies from these springs.

Below is given an assay of the water from the well of Julian Chavez. It is a shallow dug well at the margin of one of the salt basins and is filled with water virtually to the top.

Assay of water in well of Julian Chavez, near Pinos Wells, N. Mex.

[Parts per million.]

Carbonate (CO_3)	0
Bicarbonate (HCO_3)	750
Sulphate (SO_4)[a]	2,750
Chlorine (Cl)	1,350

SMALL INTERMEDIATE BASIN.

The small basin that lies between Pinos Wells and Encino basins has already been mentioned. It embraces a drainage area of only a few square miles. Its central depression is comparatively flat but still far above the ground-water level, as is proved by a deep well that has been sunk on it. Wind work has been effective here as in the larger basins, and has built a distinct clay ridge more than a mile long on the east side of the central depression. This depression, like nearly all the other wind-formed basins of this region, has a north-south elongation.

NOTES ON WELLS AT VAUGHN, N. MEX.

East of Encino Basin the surface forms in general an upland that slopes toward the Pecos Valley (fig. 1), and in parts of this upland there is difficulty in procuring enough water for domestic purposes and for the stock. In the village of Vaughn, at the intersection of the El Paso & Southwestern Railroad with the Belen cut-off of the Atchison, Topeka & Santa Fe Railway, some deep drilling has been done with poor success, and at the time the village was visited, in the summer of 1909, the inhabitants depended largely upon water hauled from Willard by the railway company. Since that time the pipe line of the El Paso & Southwestern Railroad Co. has been extended to Vaughn.

The following data have been furnished by the Atchison, Topeka, & Santa Fe Railway Co.:

[a] Turbidimeter method, by dilution.

Section of the "Epris" well, on the El Paso & Southwestern Railroad.

[Altitude of surface about 5,935 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and gravel	70	70
Red clay	50	120
Soft lime	10	130
Red clay	20	150
White lime	30	180
Red clay	46	226
Hard limestone	4	230
Red clay	30	260
White lime	30	290
Soft sand rock	36	326
Brown sand rock	14	340
White sand rock	30	370
Soft yellow sand rock	32	402
White lime	13	415
Soft white and yellow sand rock	345	760
Soft yellow sand rock (water)	71	831
Fine white sand rock	19	850
Sandy shale	47	897
Hard ledge of rock		897
Red clay	158	1,055
Clay with sand streaks	120	1,175
Red clay	75	1,250
White sand	6	1,256
Red clay	34	1,290
White sand	8	1,298
Light-colored clay	12	1,310
White sand (water)	20	1,330
Bottom of hole, June 6, 1906		1,355

Miscellaneous notes on the "Epris" well.

Depth (feet).

820 Light vein of water.

829 Vein of water which rose to 800 feet. Yield about 7 gallons per minute. The following analysis shows an extremely hard water:

	Parts per million.
Incrustants	2,678
Foaming constituents	.....
Total solids	2,807

880 The water from the depth of 1,330 feet rose to this level.

900 Light vein of water.

980 Vein of water which rose to the 900-foot level.

1,000 Depth of well November 25, 1905.

1,015 Salt water, 18 gallons in 24 hours.

1,110 Salt water, 36 gallons in 12 hours.

1,175 Salt water, 90 gallons in 12 hours.

1,200 Very little water.

1,330 From this depth is reported an analysis which indicates a strong brine.

Section of the "Tony" well, on the El Paso & Southwestern Railroad.

[Altitude of surface about 5,800 feet above sea level.]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil mixed with gypsum and bowlders	190	190
Limestone	23	213
Red gypsum and lime	18	231
Limestone	20	251
Quartzite sandstone	60	311
Yellow stone, badly fissured	450	761
Red volcanic clay	40	801
(Small vein of water.)		

The following information in regard to the "abandoned well at Vaughn on the El Paso & Southwestern Railroad" was supplied by F. M. Clough, general foreman, writing under date of December 16, 1909:

The well is 854 feet deep; size of hole, 8 inches. The water level is 600 feet from the surface. At the time this well was abandoned, about eighteen months ago, the water supply was about 600 gallons per hour. I do not have any copy of the analyses of this water. However, for your information, I will state that we gave the water a heavy treatment with caustic soda, sal soda, and soda ash, and even after this treatment the water was very bad for engine use, so we could hardly keep it in the boilers. It is a very poor quality of water, and one that could not very well be used for domestic purposes.

Surface indications of water are lacking, and the sink holes northwest of the village are unfavorable conditions. If further prospecting is undertaken, it might be best to drill in the flat west of and some distance from the quarry located northwest of the El Paso & Southwestern Railroad station.

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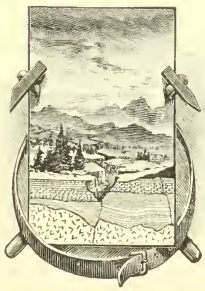
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 276

GEOLOGY AND UNDERGROUND WATERS OF NORTHEASTERN TEXAS

BY

C. H. GORDON



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GEOLOGY AND UNDERGROUND WATERS OF NORTHEASTERN TEXAS.

By C. H. Gordon.

INTRODUCTION.

GEOGRAPHY.

The area considered in this report embraces 5,989 square miles in the extreme northeast part of Texas, comprising the counties of Bowie, Red River, Lamar, Delta, Hopkins, Franklin, Titus, Morris, Camp, and Cass.

The mean annual rainfall of the region is about 48 inches, ranging from 45 inches in the west to a little more than 50 inches along the Arkansas State line. The mean annual temperature is from 64° to 65° F. The district is traversed from east to west by three lines of railroads, the Texas & Pacific (Sherman branch), the St. Louis & Southwestern, and the Missouri, Kansas & Texas. The Marshall branch of the Texas & Pacific crosses the eastern part of the region and the Texas Midland, the Gulf, Colorado & Santa Fe, and the St. Louis & San Francisco all have their termini at Paris in the northwestern part of the region.

The rich soil of the black prairie lands early attracted settlers. According to the census of 1910 the population of the 10 counties named was 198,869, or an average of 33.7 to the square mile. The western part of the region is the most thickly settled, the two blackland counties, Lamar and Delta, leading, with an average of 51.5 and 54.7 per square mile, respectively. The average for the timber-belt counties is 28.3, Hopkins and Camp leading with 46.6 and 44, respectively.

PHYSIOGRAPHY.

Lying near the outer border of the Gulf Coastal Plain, the surface of the district has in general the low rounded relief and gentle seaward slope characteristic of that physiographic province. The elevation ranges from 237 feet above sea level at Sulphur, in the northeast corner of Cass County, to 649 feet above sea level at Cumby, near the western border of Hopkins County. The crest of the divide between

Red and Sulphur Rivers has an average eastward slope of about 3½ feet per mile, descending from an altitude of 601 feet at Paris to 295 feet at Texarkana, or a total of 306 feet. South of Sulphur River the reconstructed plain surface coincident with the tops of the present hills would slope toward the southeast, and within the limits of the district would range from 649 feet at Cumby to about 320 feet near the eastern boundary of Cass County.

The region is underlain by relatively soft strata which dip gently toward the coast, and in which the present relief has been developed by the dissection of the plain surface which characterized the region on its emergence from the sea. Degradation has left few if any traces of this old land surface, the chief topographic features now presented being the rolling and hilly uplands and the flood-plain and terrace areas, the former due largely to the differential erosion of the older beds of the coastal plain and the latter represented by the flat lowlands and adjoining terrace areas composed of redeposited sediments of comparatively recent fluviatile origin.

The upland areas, which rise from 100 to 200 feet above the flat-bottomed drainage ways, present an irregular rolling topography due entirely to differences in the adjustment of erosion to the different geologic formations. The northwest portion, comprising all of Lamar and Delta counties and most of Red River County, is underlain by Cretaceous strata consisting of marls, glauconitic sands, clays, and chalk, which have been carved by erosion into an undulating surface of low relief called rolling prairie, which constitutes an integral part of the black-prairie belt of Texas. The interior of this belt is marked by a low range of hills that extends across Lamar and Red River counties, due to the greater resistance to erosion offered by the chalk formation. This range apparently constitutes an extension of the Locksburg Wold in Arkansas, described by Veatch.[1] The Saratoga Wold, also mentioned by Veatch, is somewhat obscurely represented in Delta County near Enloe. In places the chalk ridge in Lamar and Red River counties presents a low northward-facing escarpment, due chiefly to a single hard layer 4 to 6 feet thick near the top.

The upland region south of a line extending a little north of east from Commerce through Boston, the county seat of Bowie County, lies within the province known as the east Texas timber belt. This region is characterized by a range of hills which constitutes the extension into Texas of the range known as the Sulphur Wold in Arkansas. It is essentially a deeply dissected dip plain, the substructure of which consists of the sandy beds of the lower Eocene. Over a considerable part of the region the slopes are still covered with timber.

The streams have comparatively wide, flat flood plains, bounded by terraces, the highest of which has an elevation of about 90 feet

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 14–16.

above the present flood plain. These high-level terraces cover considerable areas adjoining Red and Sulphur rivers in the eastern part of the district. Between Annona and New Boston nearly all of the country between the two rivers is of this type.

A marked feature of this and adjoining parts of the Coastal Plain is the presence of low mounds composed of sand, which occur over all the region except that covered by the most recent fluviatile deposits. These mounds are commonly from 2 to 3 feet high, though a few attain a maximum height of 6 feet. Some are elliptical; most of them are circular and are from 20 to 100 feet in diameter. The tendency toward elongation appears to be more marked in some places than in others, the longer axis usually extending in a northeast-southwest direction. As remarked by Veatch, they are particularly abundant in the terrace areas, where in wet weather they form low sandy islands in the midst of a water-covered clay country.

DRAINAGE.

The drainage of the region is effected mainly by Sulphur River, which flows from west to east entirely across the district. A feature of the drainage is the greater development of the southeastward-flowing system of tributaries, those flowing to the northeast being relatively few and for the most part unimportant. From this it follows that the divides are located much nearer the main streams on the south side than on the north, and the northward-facing slopes are shorter and steeper, a feature consequent upon the general coastward slope of the original plain surface and the effort of the streams to adjust themselves to the rock structure of the region. A small area in the southern part of Hopkins County is drained by tributaries of Sabine River, and the larger part of the region lying to the east is drained into Ferry Lake through Big Cypress and other creeks. Ferry Lake connects with Sodo and Cross lakes in Caddo Parish, La., these together constituting one body of water which occupies the lower portion of the valley of Big Cypress Creek. This body of water belongs to the class of lakes in the Red River Valley whose origin is attributed to log jams.[1]

The main streams and their tributaries that have cut to the level of ground water flow throughout the year, but many of the branches are wet-weather streams only. The soft rocks over which the streams flow yield to them an abundance of fine material, which is carried in suspension for long distances, discoloring the water and forming in quieter stretches of the streams grayish or brownish red deposits.

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 60–62.

LITERATURE.

Most of the published accounts of investigations heretofore made in northeastern Texas are found in the reports of the Texas Geological Survey and of the United States Geological Survey. In two reports only are the waters of the region specially considered. Hill [1] in his exhaustive report on the geography and geology of the Black and Grand prairies of Texas gives detailed descriptions of the Cretaceous formations with special reference to the underground waters and all information available concerning the counties adjoining Red River. Veatch, in his report on the geology and underground water resources of northern Louisiana and southern Arkansas, has included some data bearing on the eastern part of the region. With these exceptions, the publications relating to the region, a fairly complete list of which follows, deal chiefly with questions of stratigraphy and natural resources other than water.

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——— Geology of parts of Texas, Indian Territory, and Arkansas adjacent to Red River: Bull. Geol. Soc. America, vol. 5, 1893, pp. 297–338. Annona, or "White Cliffs," chalk considered as belonging to higher horizon than the Austin chalk.

——— Geology and geography of the Black and Grand prairies, Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900. An exhaustive report on the Texas Cretaceous, with special reference to artesian waters.

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——— The age of the iron ores of eastern Texas: Science, vol. 23, 1894, pp. 22–25. Notes greater development of the nodular iron ore in Cass, Marion, Morris, Upshur, and Harrison counties, asserts that their age is "Lower Claiborne" or later.

——— The iron ores of eastern Texas: Trans. Am. Inst. Min. Eng., vol. 24, 1894, pp. 258–288, 862–863.

——— The Eocene Tertiary of Texas east of the Brazos River: Proc. Acad. Nat. Sci. Phila., 1895, pt. 1, pp. 89–160. Discusses the stratigraphy of the region and compares it with that east of the Mississippi as noted by Hilgard, Smith, and Johnson.

[1] Hill, R. T., Geography and geology of the Black and Grand prairies of Texas: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901.

JOHNSON, LAWRENCE C., The iron regions of northern Louisiana and eastern Texas: House Doc. No. 195, 50th Cong., 1st. sess., 54 pp., 1 map, Washington, 1888.

TAFF, J. A., Report on the Cretaceous area north of the Colorado River: Third Ann. Rept. Geol. Survey Texas, 1891, pp. 269–379; map by J. A. Taff and S. Leverett. Descriptions of the Texas Cretaceous in this paper relate chiefly to regions in the central part of the State. Contains brief discussion of estimates of depths of artesian wells in Lamar and Fannin counties (pp. 371–373).

——— and S. LEVERETT, Report on the Cretaceous area north of the Colorado River: Fourth Ann. Rept. Geol. Survey Texas, 1892, pt. 1, pp. 239–354. Continues discussion in the Third Annual Report (1891) and describes with considerable detail the occurrence and extent of the subterranean artesian basins.

——— Chalk of southwestern Arkansas: Twenty-second Ann. Rept. U. S. Geol. Survey, 1900–1901, pt. 3, pp. 685–742. Discusses the stratigraphy of southwestern Arkansas and its relation to that of Texas. Correlates the "White Cliffs" chalk with the Austin chalk of the Texas region.

VEATCH, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906. Includes many facts bearing on the geology and underground waters of northeastern Texas. Follows Hill in assigning the "White Cliffs," or Annona, chalk to a higher horizon than the Austin chalk.

GORDON, C. H., The chalk formations of northern Texas: Am. Jour. Sci., 4th ser., vol. 27, 1909, pp. 369–373. Correlates "White Cliffs" and Annona chalk with the upper part of the Austin group, the lower part being represented by the Brownstown marl.

GEOLOGIC HISTORY.

PRE-CRETACEOUS.

In the mountains of eastern Oklahoma, as shown by Taff,[1] the rock exposures appear to indicate that deposition was continuous from very early geologic time down to the close of the Pennsylvanian ("Coal Measures") epoch. Similar conditions prevailed in central Texas, where rocks representing all the divisions of the Paleozoic, with the possible exception of the Devonian, occur in conformable sequence resting upon the beveled edges of an older series of sedimentary rocks, the pre-Cambrian Llano series.[2] In western Texas and western Oklahoma these rocks grade upward without a break into deposits with Permian and Triassic affinities.

Throughout this area and to the northwest a sea existed, over whose bottom a vast thickness of sediments was laid down. The thickness of the Cambro-Ordovician in Oklahoma is estimated by Taff[1] at 12,000 feet and of the Devonian at 600 feet. Drake[3] estimates the thickness of the Carboniferous at 24,500 feet. The land mass from which these sediments were derived lay to the south and southeast, the relative positions of the land and ocean areas being thus in a sense the reverse of those now existing.[4]

[1] Taff, J. A., Atoka folio (No. 79) and Tishomingo folio (No. 98), Geol. Atlas U. S., U. S. Geol. Survey, 1902 and 1903.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 89.

[3] Drake, N. F., Proc. Am. Philos. Soc., vol. 36, 1898, p. 361.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 17.

Near the close of the Carboniferous the offshore belt of greatest sedimentation, extending from central Texas around through Oklahoma and Arkansas across the Mississippi Valley and connecting with the great trough now represented in the Appalachian chain, was subjected to profound folding and was elevated into a mountain range overlooking a sea extending to the west and to the north. Following this came a long period representing Triassic and Jurassic time, during which the elevations were worn down and the materials deposited in the adjacent seas. The lapse of time represented in the truncated edges of the folded and faulted strata was evidently very great. Then came a southward tilting of the region whereby land and water conditions were reversed and the sea transgressed northward over a relatively smooth base-leveled plain.

CRETACEOUS.

With the advent of the Cretaceous, ushered in by the northward transgression of the sea, marine sedimentation took place, the materials being derived from the land areas on the north and west. These deposits consist of alternations of sands, clays, marls, and limestones, and their character and relations show that many changes took place in the position of the shore lines and that the depth of the sea over the depressed land areas varied greatly from time to time.

If the prevailing doctrine that limestones and marls indicate deep-water conditions be strictly held, the alternations of sands, chalks, and marls of the Upper Cretaceous indicate a complex series of movements in the Texas-Arkansas region, but to interpret in terms of crustal oscillation the alternations of formations indicating quiet conditions of deposition—such as limestones, shales, and clays—seems to the writer untenable. Although the accepted doctrine may be broadly admitted, it seems probable that beds corresponding to those usually classed as deep-sea deposits may be locally formed by causes other than the lowering of the sea bottom; for instance, the shifting of currents or the extension of barriers, however produced, will be registered in the character of the formations, and such changes as these may take place locally without change of elevation. Fluctuations of level did occur, however, irregularly over the whole region, the result being a warping which caused one shore line to cut obliquely across that of a preceding period, giving rise to the present wedge-shaped outcrops with the point of the wedge directed northeast in the direction of greatest depression. These relations are well shown in the map (fig. 2, p. 18),[1] indicating the position of the shore line at different stages in the process of adjustment to the warping surface. In the early stages of advance the sea transgressed far to the west

[1] Veatch, A. C., Geology and underground-water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, fig. 3, p. 18.

over western Texas into New Mexico. At the close of the Cretaceous it had withdrawn on the west, but continued depression toward the northeast had marked out the Mississippi embayment, the submergence of which continued into late Oligocene time. Owing to the transgression of the shore line in the Mississippi embayment, accompanied by the withdrawal of the sea on the west, the earlier formations are overlapped by the later, and in consequence the outcrops wedge out toward the northeast, in Arkansas.

POST-CRETACEOUS.

Upon the Upper Cretaceous beds in the south half of the district lie sands, clays, and ferruginous sandstones belonging to the Eocene. No stratigraphic break has been recognized between the two systems. Originally, the Eocene doubtless extended much farther north, covering the whole of the area here considered, the present exposures of the lower formations being due to the removal of the Eocene sediments by erosion.

At the beginning of the Eocene there was evidently a slight warping of the surface which allowed the ocean to advance farther up the Mississippi embayment than before. As a result the early Eocene beds slightly overlap upon the Cretaceous, though no stratigraphic break marks the close of the Cretaceous in the Gulf region. A marked change appears in the animal life, however, an entirely new fauna making its appearance. Dana suggests [1] that this abrupt change in animal life is perhaps due to an alteration in the direction and character of the ocean currents, with the consequent change in temperature and food supply, and to the destructive effects of earthquake waves resulting from the gigantic disturbances which produced the Rocky Mountains rather than to a time lapse.

Throughout the region in the epoch succeeding the Midway—that is, in the interval represented by the Wilcox formation, of the Eocene series—near-shore or swampy conditions prevailed with an occasional submergence by the ocean.

No Oligocene or Miocene deposits have been recognized in this part of northeastern Texas. The Miocene was essentially a period of erosion in this region, and if deposits of Oligocene age were laid down here they were largely removed during the Miocene epoch.

During the succeeding epoch (Pliocene) a mantle of sand, silt, and gravel was spread over the eroded surface. Again erosion followed, during which much of the material previously deposited was carried away or rearranged at lower levels. Pleistocene deposition succeeded, giving rise to marine sedimentation along the coasts and fluviatile deposits on the land (Port Hudson formation). This was

[1] Manual of Geology, 4th ed., 1895, pp. 877–878.

followed by another period of erosion, in which the present flood plains and principal terraces were formed, this constituting the closing stage of the Pleistocene. The present cycle is represented in the surficial flood-plain deposition and hill-land erosion now in progress.

GEOLOGY.

The geologic formations that outcrop in the district may be classed as (1) Upper Cretaceous, (2) lower Tertiary, and (3) surficial deposits. The Cretaceous includes the Comanche series (Lower Cretaceous) as well as the Gulf series (Upper Cretaceous), but only the latter appears at the surface in the district.

CRETACEOUS SYSTEM.

COMANCHE SERIES (LOWER CRETACEOUS).

Lower Cretaceous beds do not appear at the surface in northeastern Texas, but outcrop in eastern Oklahoma on the north side of Red

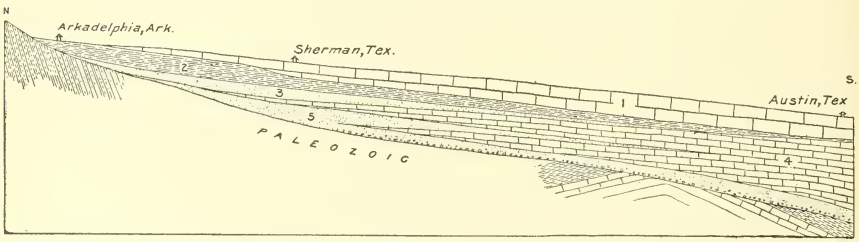


FIGURE 1.—Diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas. (After Taff.) 1, White chalk; 2, blue marl; 3, sands at base of Upper Cretaceous; 4, Lower Cretaceous limestone; 5, sand at base of Lower Cretaceous. Reproduced from Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

River and farther northeast, in Arkansas. The lowest formation, known as the Trinity sand, is composed of fine, clean sand with occasional pebbles and bowlders of white quartz and other crystalline rock derived from the old Paleozoic land surface. In some places the sands are interlaminated with thin layers and lenses of clay; in other places they contain vegetal remains and brackish-water shells. Throughout a large portion of the Black and Grand prairie region in Texas this formation constitutes an important water-bearing stratum, which supplies thousands of artesian wells, many of which flow. In northeastern Texas, however, the southward dip of the strata has carried these sands too far below the surface to be conveniently reached by the drill except in a relatively narrow belt along the south side of Red River in Lamar and Red River counties.

The Trinity sand, which represents near-shore deposits, is succeeded upward by the limestones and marls of the Fredericksburg and Washita groups, a change indicative of deeper water. The Fredericksburg group is represented by the Goodland limestone

and the Washita group by the Denison formation, Fort Worth limestone, and Preston formation. As the sea in which these sediments were deposited progressed northwestward upon the sinking land surface the lime formations lapped upon and graded into the sandy shore formations and hence are much thinner in this region than in the southern part of the State.

The stratigraphic relations are shown in figure 1 (p. 14).

GULF SERIES (UPPER CRETACEOUS).

CLASSIFICATION.

The sequence and lithologic character of the formations composing the Upper Cretaceous in northeastern Texas is shown in the accompanying table, which includes also Veatch's table for western Arkansas. The correlations are suggested by the author. Veatch considers the Annona and Brownstown to be equivalent to the lower part of the Navarro and Taylor, and the Bingen to be the littoral equivalent of the Woodbine, Eagle Ford, and Austin.

Classification of the Upper Cretaceous in northeastern Texas and southwestern Arkansas.

Northeastern Texas (Gordon).			Southwestern Arkansas (Veatch).		
Formations.		Character of rocks.	Formations.		Character of rocks.
Navarro formation and Taylor marl.	Arkadelphia clay.	Dark-blue to black laminated clays. Sulphur Bluff.	Arkadelphia clay.		Black laminated clays.
	Nacatoch sand.	Green sands grading into marls below. Delta County.	Nacatoch sand.		Sand with occasional quartzitic layers.
	Marlbrook marl.	Sandy and clay marls. Chalk at Enloe Sands near Ladonia. Blue marly clay.	Marlbrook marl.		Very calcareous clay with marine fossils.
Austin group.	Annona chalk.	White chalk.	Annona chalk.		White chalk.
	Brownstown marl.	Blue clay marl.	Brownstown marl.		Blue calcareous clay.
Eagle Ford clay.	Blossom sand member.	Sands and sandy clays interlaminated.	Sub-Clarksville sand.	Bingen sand.	Water-bearing sand.
	.....	Dark laminated clays.	Eagle Ford clay.		Blue calcareous clay.
Woodbine sand.	.....	Lignitiferous sands, sandy clays, and sandstones.	Woodbine sand.		Lignitiferous sands and clays with plant remains.

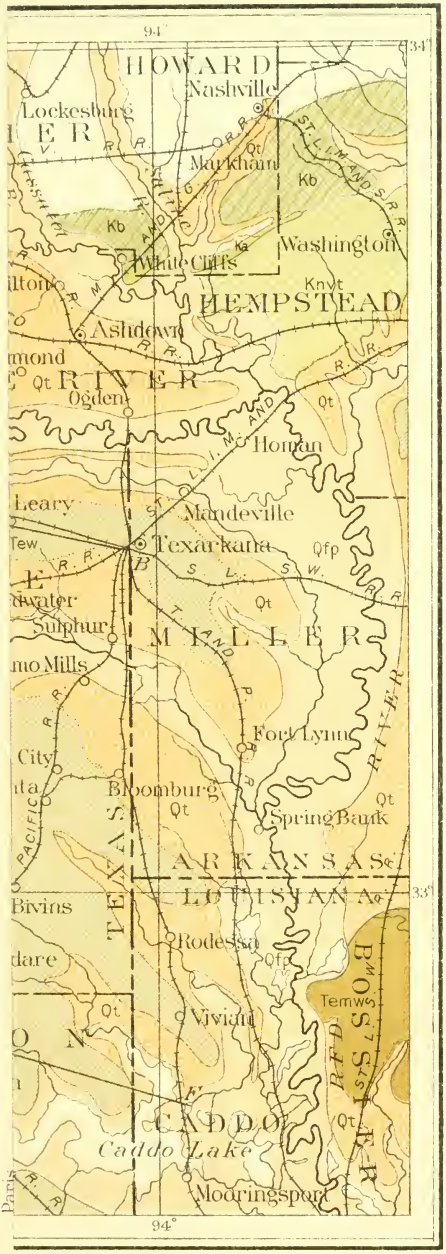
With the exception of the chalks, the rocks are characterized for the most part by a general lack of consolidation. The marls and clays especially disintegrate readily, yielding a thick mantle of black soil through which the underlying formations rarely protrude. No stratigraphic breaks occur within the Upper Cretaceous, and the gradations between its different formations is so gradual that these can be mapped in most places only with the greatest difficulty, if at all.

The chief exposures of the rocks of the gulf series occur in the northwestern part of the area between South Fork of Sulphur River and Red River. Farther east, in Texas, these formations are covered by surficial deposits which consist largely of unconsolidated sands, clays, and marls, and some indurated beds of sandstone and chalk. The beds dip southeastward at a low angle, at a rate of about 50 to 55 feet per mile, in the district north of North Fork. In their eastward extension and also where they lie under cover toward the south, as indicated by the few well records available, they appear to have a steeper dip.

WOODBINE SAND.

The Woodbine consists of ferruginous and argillaceous sands accompanied by bituminous laminated clays. The sands are for the most part unconsolidated and contain many remains of plants, a feature which distinguishes them from other Upper Cretaceous formations. When unweathered the sands appear white and friable, but contain more or less iron in the form of pyrite and glauconite as well as other ingredients, which on decomposing materially affect the character of the waters derived from them. In places solutions of the oxidized iron minerals have consolidated the sands into dark-brown ferruginous sandstone or siliceous iron ore. In large part the sands break down into deep loose soils. The clays are laminated and are for the most part impure, sandy, and lignitic. In northeast Texas the formation is characterized by the presence of argillaceous and calcareous layers interlaminated with the sand and by the occurrence of plant remains in considerable numbers, together with a peculiar molluscan fauna. A large part of the plant collection noted by Hill was obtained by Vaughan at Arthurs Bluff on Red River in Lamar County.

The Woodbine sand underlies the area adjacent to Red River in the northern part of Lamar and Red River counties and as far west as Dexter in Cooke County. From Red River it extends southward coextensively with the lower cross-timber country, but has not been recognized south of Brazos River. The region of its outcrop is generally characterized by a loose sandy soil, mostly covered with coarse post-oak and black-jack timber, here and there broken by small prairies where the beds contain an increased proportion of clay. From Red River to the Brazos the western boundary of the belt is marked by a range of low hills and knobs whose existence is due to the greater resistance to erosion offered by the more consolidated ferruginous beds of the lower part of the formation (called Dexter sand by Taff and Hill). The Woodbine is traversed for miles by Red River, but owing to its unconsolidated character and its covering of timber and alluvial deposits exposures of it are infre-



Geology by C. H. Gordon

LEGEND

SURFICIAL DEPOSITS

Recent

Qfp — Flood-plain deposits (recent silts and clays)

Pleistocene

Qt — Port Hudson formation (Sands, silts, and clays)

CONSOLIDATED SEDIMENTS

Eocene (TERTIARY)

Tew — Wilcox ("Sabine") formation (lignitiferous sands and clays)

Temw — Midway and Wilcox formations undifferentiated (clays with some sand and limestone)

Upper Cretaceous (Gulf series) (CRETACEOUS)

Knvt — Navarro formation and Taylor marl undifferentiated (Clay, glauconitic sands, calcareous marls with some chalk)

Arkadelphia clay, Nacatoch sand, Marlbrook marl in southwestern Arkansas

Austin group

Ka — Annona chalk

Kb — Brownstown marl

Eagle Ford sand in southwestern Arkansas

Kefb — Kefl — Eagle Ford clay (clay with lenses of limestone and at top Bilossom sand member (Kefb))

Buda sand in southwestern Arkansas

Kw — Woodbine sand (with lentils of clay)

Lower Cretaceous (Comanche series) (CRETACEOUS)

Washita group

Kd — Denison formation (limestone and shales)

Kf — Fort Worth limestone (limestone with some shales)

Kp — Preston formation (limestones and shales)

Fredericksburg group

Kg — Goodland limestone

Kt — Trinity sand (sands and laminated clays)

QUATERNARY

U S GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC MAP OF NORTHEAST TEXAS

Scale 1:1,000,000

10 0 10 20 30 40 Miles

1911

Base drawn mainly from post-route map of Texas, 191
Survey of Cypress Bayou and Caddo Lake by the War
Department 1892 and other sources

Geology by C. H. Gordon

LEGEND

SURFICIAL DEPOSITS

QUATERNARY

Recent

Qfp — Flood plain deposits (recent silts and clays)

Pleistocene

Qt — Port Hudson formation (Sands, silts, and clays)

CONSOLIDATED SEDIMENTS

TERTIARY

Eocene

Tew — Wilcox (Sabine) formation (lignitiferous sands and clays)

Temw — Midway and Wilcox formations undifferentiated (clays with some sand and limestone)

Knvt — Navarro formation and Taylor marl undifferentiated (clay glauconitic sands calcareous marls with some chalk)

CRETACEOUS

Upper Cretaceous (Gulf series)

Austin group

Ka — Annona chalk

Kb — Brownstown marl

Eagle Ford group

Kefb — Kef — Eagle Ford clay (clay with lenses of limestone and at top Bloxom sand member (Kefb))

Woodbine sand

Kw — Woodbine sand with lentils of clay

Lower Cretaceous (Comanche series)

Fredericksburg group

Kd — Denison formation (limestone and shales)

Kf — Fort Worth limestone (limestone with some shales)

Kp — Preston formation (limestones and shales)

Washita group

Kg — Goodland limestone

Kt — Trinity sand (sands and laminated clays)

Jurassic

Upper Jurassic

Bingen sand in southwestern Arkansas

Lower Cretaceous Arkadelphia clay Nacatoch sand Marlbrook marl in southwestern Arkansas

quent, occurring only in undermining bluffs, as at Arthurs Bluff north of Paris and at Pine Bluff in the northeast part of Lamar County. At Rock Ford, in Red River County, sand, in part glauconitic, occurs in the bluffs, which also show near the top several layers of white fossiliferous limestone. The area in which the Woodbine outcrops in northeastern Texas is shown approximately on the map (Pl. I).

In this region the formation has an estimated thickness of 600 to 800 feet. In the Paris well the drill penetrated 820 feet of sand and clay beds which have been assigned to the Woodbine; some of the lower beds, however, may belong to the underlying Denison formation. Southward it diminishes in thickness until it disappears by overlap in the vicinity of the Brazos. Eastward in Arkansas the Woodbine, there called the Bingen sand, coalesces, according to Veatch,[1] with the sands at the top of the Eagle Ford (Blossom sand member) by the thinning out of the intervening Eagle Ford clay. According to Veatch, therefore, the Bingen sand, which is the lithological counterpart of the Woodbine sand in Texas, is the time equivalent of all the beds of the Upper[2] Cretaceous below the Brownstown marl. (See fig. 2.)

As the Brownstown was considered by Veatch to lie immediately above the Austin chalk, the conclusion was drawn that the Bingen sand contained the littoral equivalents of the Austin and the Eagle Ford.[3]

EAGLE FORD CLAY.

Character.—The lower two-thirds of the Eagle Ford formation in northeastern Texas consists chiefly of dark, laminated clays, and the upper 50 to 75 feet is made up of brown, ferruginous, glauconitic sands interlaminated with clay. Inasmuch as the upper sandy beds constitute a water horizon of some value, a subdivision of the formation based on lithological distinctions seems warranted. To the upper sandy portion, therefore, the term Blossom sand member is applied, from the town of Blossom, which is located in eastern Lamar County upon the outcrop of the beds.[4]

Thickness.—The total thickness of the Eagle Ford clay in this region, as recognized in the Paris well section (p. 45), is 600 feet. This well is located directly upon the outcrop of the Blossom sand member and it doubtless includes very nearly the full thickness of the beds. Eighty feet of the sands was penetrated, the whole of

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 23–24.
[2] Veatch says "Lower" Cretaceous, but this is evidently a typographical error.
[3] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 18.
[4] Am. Jour. Sci., 4th ser., vol. 27, 1902, pp. 371, 373.

which with the exception of a few feet of soil is regarded as representing the Blossom. The formation thins rapidly eastward, there being but 174 feet of hard sands that can be referred to this formation in the Texarkana well (p. 59), east of which it is not known.

Fossils.—As a whole the Eagle Ford is not very fossiliferous except in the upper arenaceous division (Blossom sand member). A few

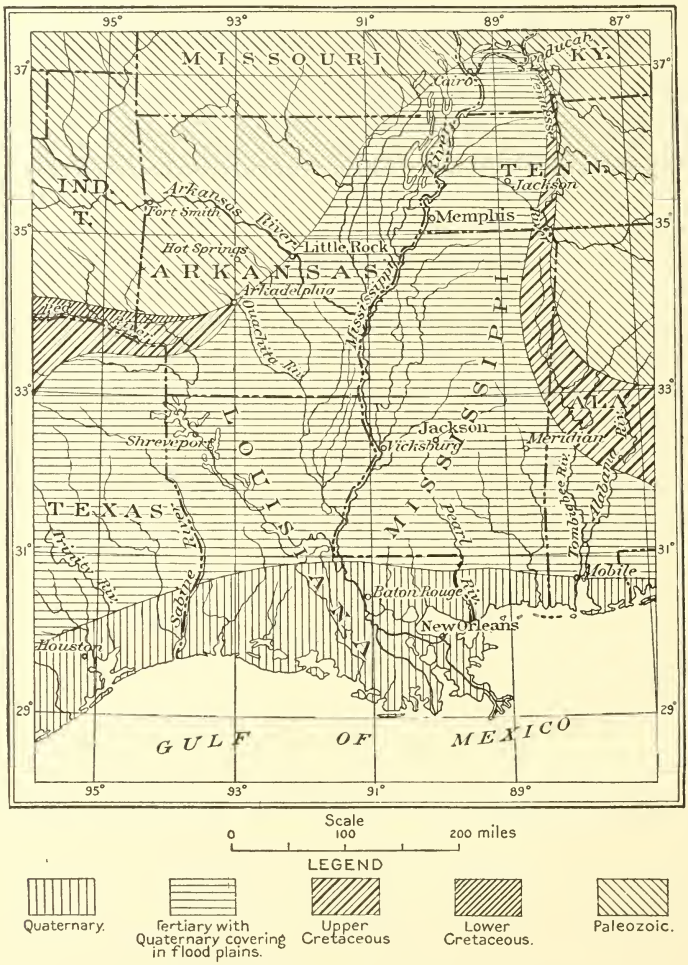


FIGURE 2.—Map showing overlap of Upper Cretaceous on Lower Cretaceous and of Tertiary on Cretaceous in the Mississippi Valley. (After Veatch.)

forms of Ammonites preserved with their nacreous shell coloring occur sparingly throughout the formation, and the blue limestone concretions are generally filled with the remains of certain invertebrate forms. In addition to an abundance of fish remains, chiefly teeth, the Blossom sand member contains an abundance of the characteristic forms *Ostrea lugubris* = *O. belli plicata*, *Inoceramus fragilis*,

I. labiatus, and a small form like *O. congesta*. Hill[1] gives the following list of fossils obtained from the Eagle Ford formation:

Planticeras syrtalis Mort. var. cumminsi Cragin.
Ammonites woolgari Mort.
Sphenodiscus dumblei Cragin.
Buchiceras inequiplicatus Shumard.
B. swallowi Shum.
Tapes hilgardi Shum.
Anchura modesta Cragin.
Fusus graysonensis Cragin.
Natica striatacostata Cragin.
Neritopsis biangulatus Shumard.
Ostrea lugubris Conrad=O. belliplicata Shum.
Ostrea sp. (like O. congesta).
Inoceramus fragilis Hall and Meek.
I. labiatus Schlotheim.
Fish teeth.

Lower clays.—The lower part of the formation consists essentially of blue and black laminated bituminous clays accompanied by thin laminated clay limestones and nodular septaria of blue limestone; thin laminæ of sand occur in this portion, showing a gradual transition from the Woodbine sand below. The central and larger part of the formation is made up of blue and black marly clays, which include thin beds of arenaceous limestone and numerous hard nodular septaria, some of which attain a diameter of 3 feet; these septaria are composed of dense blue limestone with cross fissures filled with calcite and selenite. Selenite in minute crystals is disseminated generally through the clays, in places in considerable quantities, and the water flowing through these beds is generally bitter and disagreeable to the taste.

The clays constitute a belt of prairie extending east and west across Lamar and Red River counties north of the Texas Pacific Railway, and bounded on the north by the Woodbine sand and on the south by a narrow strip of sandy land representing the outcrop of the Blossom sand member. The outcrops of the clay make the black waxy land north of Paris.

Blossom sand member.[2]—The clays of the Eagle Ford grade upward into brown sandy ferruginous glauconitic beds interlaminated with thin beds of clay. The clays are filled with fossiliferous concretionary masses of limestone similar to those in the middle part of the formation; in places these weather out as bowlders. Locally the sands are highly fossiliferous, some layers being composed in large part of the casts of shells. The full thickness of these beds was not observed in the area to which this report relates, but at Sherman (2 miles west of the area) the following succession occurs.[3]

[1] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, p. 328.

[2] Blossom sand member = "sub-Clarksville" sand of Veatch, Prof. Paper U. S. Geol. Survey No. 46. "Fish beds" of Taff and Hill=Blossom sand member (in part). *Ostrea belliplicata* bed of Taff=Blossom sand member (in part).

[3] Hill, R. T., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 326.

Section of Blossom sand member at Sherman, Tex.

	Feet.
6. Sandy clay shales with *Ostrea lugubris*	10
5. Thin slabs of brown sandstone with rounded conglomerate of jasper pebble. *Ostrea lugubris* and fish teeth	5
4. Blue laminated clay, weathering into limonitic colors	10
3. Massive agglomerate of shells of *Ostrea lugubris*	2
2. Sandy clay shale in thin alternations of clay and sand; clay efflorescent and drab colored on drying; contains *Ostrea lugubris*.	40
	67

The description given in the section of the beds at Sherman corresponds well with the character of the strata as they appear in Lamar and Red River counties.

The outcrop of the Blossom sand member extends in a band approximately a mile in width from a point nearly north of Annona, where Pecan Bayou intersects the bluff of Red River, to the western limit of the area, except where interrupted by overlying Quaternary formations. Outcrops occur at different places along the south side of Pecan Bayou, which flows for the greater part of its course on the formation; and in Lamar County they appear almost continuous along a line through Blossom and Paris, both of which places are located upon these beds. On the south the sands are bounded by the black waxy soils derived from the marly clays of the Brownstown marl, the lower formation of the Austin group. Four miles north of Clarksville the contact of the Blossom sand member with the overlying Brownstown marl was observed in a ravine. The section obtained here was as follows:

Section in ravine 4 miles north of Clarksville.

Brownstown marl:	Feet.
7. Clay marl with an abundance of *Exogyra ponderosa* in the lower 12 inches	6
Blossom sand member of Eagle Ford clay:	
6. Sand, in places mixed with marly clay	3
5. Blue marly clay (exposed)	6
4. Covered (about)	10
3. Yellow sand with fossil impressions	10
2. Drab fissile clay	2
1. Yellow sand above, grading into drab arenaceous clay below. Contains iron concretions showing impressions of fossils	20
	57

From 10 to 20 feet below the top of these beds in Grayson County, as described by Taff,[1] is a bed of coarse sand or grit, in places a conglomerate, called the "Fish bed," from the large number of fish teeth contained in it. This bed was not definitely recognized in Lamar and Red River counties. The beds are generally highly fos-

[1] Taff, J. A., Fourth Ann. Rept. Geol. Survey Texas, p. 303.

siliferous, though in general the material is in a friable condition, owing to weathering and oxidation. Ostreas (*Ostrea lugubris=O. belliplicata*) are numerous and in places farther west make up most of certain beds to which the term "shell bed" very appropriately applies.

The Blossom sand member, though comparatively insignificant stratigraphically, is important, because it constitutes the only available water-bearing horizon over a considerable portion of south Lamar and Red River counties. It is from this sand that the water supply at Clarksville is obtained, a fact which, in the absence of known outcrops, led Veatch [1] to give it the name "sub-Clarksville" sand. At Paris, according to the well record given on page 45, these sands have a thickness of 80 feet.

AUSTIN GROUP.

General character and relations.—From Sherman in Grayson County southward to the Colorado in Travis County the Austin chalk constitutes the most persistent and characteristic formation of the Cretaceous in Texas. Throughout this area its thickness is estimated by Taff to be about 600 feet. From the base to the top the rock consists for the most part of soft bluish-white chalk, chiefly in beds from 2 to 6 feet thick, interspersed here and there by a succession of thinner layers. The beds are generally separated by very thin sheets of calcareous marl, which in places thicken to 3 to 12 inches. Toward the top the beds become more massive, being from 4 to 6 feet thick, with very little separating marl between them.

Interstratified with the soft layers in places are nonpersistent harder arenaceous layers, which on weathering project in rounded subangular surfaces.

On weathering, the chalk loses the bluish cast seen in fresh exposures and becomes white or cream colored. It usually has an earthy texture and when fresh can be readily cut with a handsaw. Here and there nests of pyrites and crevices filled with calcite appear. Under the microscope [2] the material shows calcite crystals, minute amorphous calcite, and the shells of foraminifers, mollusks, echinoids, and other marine organic débris such as usually constitute chalk formations.

From Sherman eastward the basal portion of the Austin becomes more argillaceous and assumes the character of clay marl or marly clay. Beginning at the base in the vicinity of Sherman this change in character reaches higher and higher as the formation extends eastward until at Atlas, Clarksville, and White Rock north of Annona in Texas and at White Cliffs in Arkansas only the uppermost beds pre-

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 25.

[2] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 329.

sent the character of true chalk. Among previous writers Taff[1] seems to be the only one who recognized the true relations of the chalk deposits of northeastern Texas and southwestern Arkansas. The statements by this author accord so well with the independent conclusions of the writer that they are given entire:

> The lower part of the chalk formation of northern Texas changes to marl in the vicinity of Sherman, and still farther east higher beds successively become chalky marl, so that within a comparatively short distance only the upper part of the chalk formation as it occurs farther south is true chalk. In other words, the white chalk transgresses upward in the series of Cretaceous rocks from the vicinity of Sherman, Tex., eastward into Arkansas.
>
> The fossils of the main chalk which are not found below the chalk in northern Texas south of Sherman occur in the chalky marl beneath the chalk from the vicinity of Paris, Tex., eastward. The fauna, including the characteristic species of fossils, such as *Exogyra ponderosa*, *Gryphæa vesicularis*, *Astrea larva*, and others which occur only in the upper beds of the chalk in central Texas, are found in great abundance in the marl at the base of and beneath the white chalk in southwestern Arkansas.[2]
>
> This chalk grows thinner in outcrop northeastward as it approaches the Paleozoic border and elevated mountain districts until it ends in chalky marl near the center of the Cretaceous area of southwestern Arkansas.

Hill[3] considered the chalk near Annona and westward as representing a higher horizon than the Austin chalk, which he describes as having largely thinned out east of Paris, but says that its exact relationship is subject to later determination. To the marls underlying the chalk at White Cliffs, Ark., which he rightly considered the equivalent of the lower part of the Annona chalk, he gave the name Brownstown. Veatch[4] appears to have accepted Hill's conclusions in assigning the Annona chalk to a higher horizon than the Austin, which he states does not appear east of Paris, Tex. In this he differs, however, from Hill, who states that "the most eastern outcrop of this chalk [Austin] is in Little River County, in the southwest corner of Arkansas."[5]

The field work of 1906 and 1907 having settled conclusively that the Annona chalk corresponds to the upper beds of the Austin, and that the underlying Brownstown marl is the eastern equivalent of the lower portion of the same formation, it seems appropriate to include both of these under the term Austin group.

Brownstown marl.—In Red River and Lamar counties and west to Sherman the Blossom sand member, constituting the uppermost beds of the Eagle Ford clay, grades rather abruptly into the light-blue calcareous and sandy clay or marl (Brownstown) representing the lower formation of the Austin group. Toward the top the proportion of lime increases, so that the upper beds are decidedly chalky and in places

[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1900–1901, pp. 698–700.

[2] The writer's observations show these fossils to be present in northeastern Texas from the marls at the base of the chalk up to the marls of the Navarro formation.

[3] Hill, R. T., op. cit., p. 341.

[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 19.

[5] Hill, R. T., op. cit., p. 330.

grade horizontally into true chalk. This variation in the composition of the Austin group gives rise to variation in the relative thickness of the chalk and marl divisions and in the relative width of their outcrops, the one varying inversely as the other. Four miles south of Paris the marls appear on fresh exposure bluish-white and chalky, much resembling chalk, but softer. On weathering they become drab to yellowish-brown, grading upward into a black waxy soil. The lower portions are more arenaceous, forming along the northern border of the formation outcrop a strip of soil called "mixed land" or "tallow-ridge land." The width of the outcrop of the marls south of Paris is from 5 to 6 miles, indicating a thickness of about 300 feet, while that of the overlying chalk on the south is correspondingly lessened. The chalk belt widens toward the east and west, the marl belt narrowing to a mile or less north of Annona. The marls here pass under the later Quaternary deposits along with the overlying Annona and higher beds, but they evidently thicken rapidly eastward, for according to Veatch they have a thickness in southwestern Arkansas of 600 feet, thinning out again to about 150 feet in the eastern part of the area.[1]

The name Brownstown, as shown by Veatch, was first applied by Hill [2] to marl beds typically developed at Brownstown, Ark., the stratigraphic position of which was not recognized until later.[3] As now defined, the term includes the blue marly clays and clay marls between the Blossom sand member of the Eagle Ford and the Annona chalk in Texas and the equivalent beds in Arkansas which rest upon the Bingen sand, which is considered to be the representative of the Eagle Ford clay and the Woodbine sand as developed in Texas.

Annona chalk.—The chalk beds constituting the upper formation of the Austin group in northeastern Texas were named Annona chalk by Hill,[4] who correctly recognized their equivalency to the chalk occurring on Little River in Arkansas, to which he had previously applied the term White Cliffs chalk.[5] The formation consists of bluish and creamy white chalk similar to the corresponding beds of the Austin chalk farther south. At White Cliffs, Ark., the chalk beds are about 100 feet in thickness and underlain by argillaceous chalk marl grading downward into sandy chalk marl.[6] The exposures in Texas are less

[1] Veatch, A. C., op. cit., p. 25.

[2] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 2, pp. 86–87; Bull. Geol. Soc. America, vol. 1894, p. 302, pl. 12.

[3] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340.

[4] Hill, R. T., Bull. Geol. Soc. America, vol. 5, 1894, p. 308 (there spelled Anona); Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 340–341. In the former paper Hill says: "It is not known what has become of the Austin chalk in this section (Paris), but my hypothesis, backed by some evidence, is that to the southward it has been faulted down. The Annona (White Cliffs) chalk is an entirely distinct and higher bed." In the later publication he says: "The writer has considered this chalk (Annona) to represent a higher horizon than the Austin, but its exact relationship is subject to future determination."

[5] Hill, R. T., Ann. Rept. Geol. Survey Arkansas for 1888, vol. 1888, pp. 87–89.

[6] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 706–707.

extensive, but so far as can be determined the rock presents essentially the same characters near Annona and westward to Sherman.

The first appearance of the chalk in Texas is to the north of Annona in Red River County, from which place it takes its name. At this point its outcrop is about 4 miles in width and is cut off on the east by deposits of Quaternary age. From this point the chalk extends west through Clarksville, Atlas, and Roxton in Lamar County, and thence west to Sherman. From Atlas the northern border swings northward to Petty on the Texas & Pacific Railway, thence westward about a mile north of Honey Grove. About 3 miles west of Clarksville the exposures of chalk and accompanying marls are interrupted by Quaternary deposits, partly filling a broad shallow valley now occupied by the headwater branches of Cuthand Creek.

The composition of the chalk is shown by the following analyses:

Analyses of the Austin chalk.

	1	2	3	4	5
Calcium carbonate	82.51	84.48	84.14	90.15	70.21
Silica and insoluble silicates	11.45	9.77	10.14	5.77	23.55
Ferric oxide and alumina	3.61	1.25	4.04	2.14	1.50
Magnesia	1.19	Trace.	[a]1.68	.58	.58

[a] Mg and H_2O.

1. Texas chalk; locality not given. Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1899–1900, p. 329.
2. Rocky Comfort, Arkansas (Annona chalk). Idem.
3. Annona chalk, 7 miles south of Paris. Analysis furnished by J. A. Porter, Paris, Tex.
4. Quarry of the Alamo Cement Works, 3 miles north of San Antonio, Tex. Average material used in the manufacture of cement. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.
5. Average fresh rock from quarry of the Texas Portland Cement Works, 3 miles west of Dallas, Tex. Lower 20 feet of white chalk. Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.

With complete disintegration the Annona chalk breaks down into a black waxy soil similar to that of adjacent formations. As a rule, however, owing to its greater hardness, the soil is thin and less productive than adjoining areas. Over the area where it constitutes the surface formation its outcrops are conspicuous in all the slopes and drainage ways by reason of their glaring white color.

The Austin chalk is characterized by many fossils, of which large specimens of *Inoceramus cripsi* var. *barabini* Morton and *Exogyra ponderosa* Roemer are conspicuous from the base to the top. As these fossils occur also in the formations above the Austin, they do not constitute a reliable means of discrimination. Hill has given several other forms as occurring in the Austin, such as *Exogyra læviuscula* Roemer, *Gryphæa aucella* Roemer, and *Hemiaster texanus* Roemer.[1]

The thickness of the Austin group as revealed by the Clarksville wells corresponds closely with the estimate given by Taff for the

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 336.

central Texas region (p. 21). In the Clarksville wells the water-bearing sands (Blossom sand member) were reached at a depth of about 600 feet. The drill is reported to have passed through "white rock" all the way, the lower portion being softer. As the wells are located very near the top of the Annona chalk, these figures may be considered a close approximation of the thickness of the Austin group in this locality.

TAYLOR MARL AND NAVARRO FORMATION.

Attempted differentiations.—Above the Austin group occurs a series of beds of calcareous clays, chalky marls, and greensands, the differentiation of which is rendered extremely difficult by reason of the unindurated character of the material and the consequent lack of good exposures.

Numerous efforts have been made by Hill and others to classify these beds, but the results have been unsatisfactory. Taff [1] divided the Cretaceous rocks above the Austin chalk in central Texas into (1) Greensand marl; (2) Marly flags, 100 feet; (3) *Ponderosa* marl, 1,000 feet; and (4) Chalk marl, 100 feet. In his latest report on the Texas Cretaceous, Hill divided the Upper Cretaceous into two divisions, the lower of which he called the Taylor marl and the upper the Navarro formation, a name originally proposed by Shumard. In northeastern Texas he divides [2] the Navarro into Arkadelphia beds, Washington beds, Annona chalk, Roxton beds, and Brownstown beds. As it is now clear that the Annona and the Brownstown represent the Austin, the overlying Taylor marl must be represented in part at least by the marls overlying the Annona, to which Hill originally applied [3] the name "Kickapoo." He states that the formation bears a growth of hardwood, including Bois d'Arc, and adds "this is the only marly terrane in the entire range of Cretaceous formations in Texas which is covered by arborescent vegetation."

In Arkansas the equivalents of the Navarro and Taylor formations, as made out by Hill and Veatch, are as follows:

Arkansas equivalents of the Navarro formation and Taylor marl.

3. Arkadelphia clay: Dark laminated clays; 200 to 500 feet.

2. Nacatoch sand: Glauconitic sands and thin ledges of calcareous sandstones; 60 to 160 feet.

1. Marlbrook marl: Blue chalky glauconitic marls; in places, impure chalk. A chalky layer, 20 to 50 feet thick, which occurs 200 to 300 feet above the base, is called the "Saratoga" chalk member. Thickness, 50 to 750 feet.

[1] Third Ann. Rept. Texas Geol. Survey, 1891, pp. 354-359.

[2] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 340. In describing the "Washington beds" the author states that they "surmount the Brownstown marls," evidently an error carried over from his earlier descriptions wherein the Brownstown marl was considered as being above the Annona chalk.

[3] Hill, R. T., Bull. Geol. Soc. America, vol. 5, p. 308, 1893.

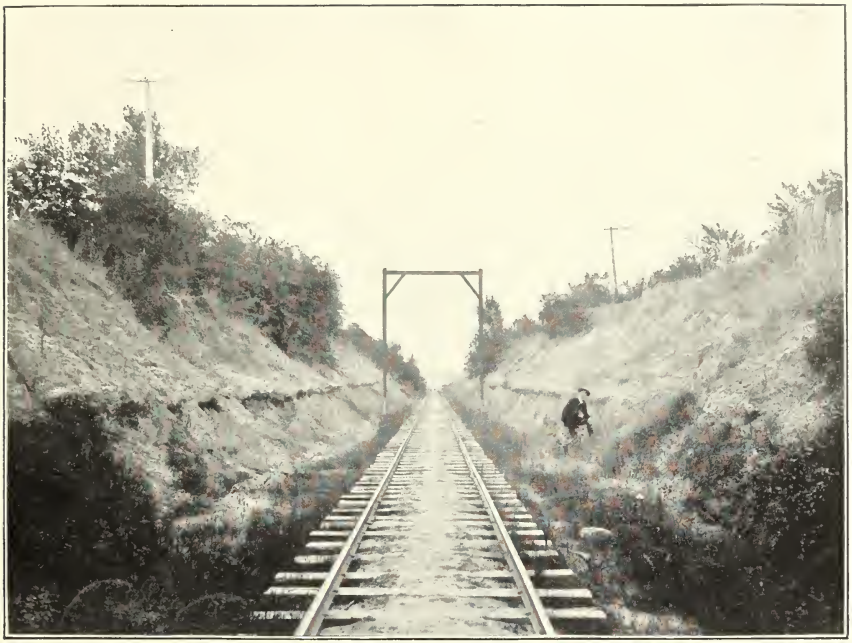
Hill recognizes two lithologic phases of the upper part of the Navarro in the region north of the Brazos. The lower division, called by him the "Corsicana beds," consists of brown sandy marl with an occasional bed of hard, calcareous sandstone. Limestone concretions and a few bands of limestone occurring in these beds suggest the formations occurring in the vicinity of Cooper, Delta County. The upper division, which he called the "Kemp beds," consists of a yellow clay with nodules which apparently corresponds to the beds observed one-half mile north of Sulphur Bluff. However, very little information is available concerning the relation of these beds.

Character and thickness.—No satisfactory data bearing on the thickness of the Navarro and Taylor formations in this region are available. They are estimated to have a combined thickness of about 1,000 to 1,200 feet. The Sulphur Springs well shows 381 feet of blue shale with some sand, which evidently represent in part the Arkadelphia clay and Nacatoch sand.

Although well-marked correspondence with the Arkansas section can be made out in the character and sequence of the formations in Delta and adjoining counties, the lack of good exposures due to the unconsolidated character of the beds renders the definition of formation boundaries impracticable, and the whole is mapped as a unit.

At the base of the section in southern Lamar County a clay marl containing varying proportions of sand, and having an estimated thickness of 100 to 150 feet, forms a deep black soil in which no outcrops appear. This marl grades upward into fine marly sands containing thin ledges of limestone or chalk. These beds are exposed at Ladonia (Pl. II, *A*), Wolfe City, and elsewhere along a narrow belt extending from the northeast part of Delta County westward along the south side of North Fork as far west as Ladonia and thence southwestward through Wolfe City. Above the sands lies a highly calcareous marl or impure chalk, 20 to 50 feet thick, corresponding in position and character to the "Saratoga" chalk member of the Arkansas section. These beds are exposed in the slopes of North Fork about 2 miles north of Enloe, south of Ladonia, and in the vicinity of Fairlie in Hunt County.

The chalky beds grade upward into unconsolidated arenaceous marls in which occur concretionary masses of dense blue fossiliferous limestone. These marls constitute much of the surface of Delta County, but owing to the readiness with which they succumb to the weather exposures of unaltered material are rare. The estimated thickness of the marls is 350 to 500 feet, but as no wells extend through them in this region the data on which to base an estimate are very imperfect. Toward the south the black lands representing the outcrop of the marls give place to sands the exact relations of which are not clear, but which represent apparently the horizon of the



A. RAILROAD CUT AT LADONIA STATION.

Exposures of fine, marly sands containing thin ledges of limestone or chalk representing a part of undifferentiated Navarro-Taylor marl division. (See p. 26.)

B. RAILROAD CUT AT AVINGER STATION.

Exposure of sands and clays of Wilcox ("Sabine") formation.

Nacatoch sand, though some doubt exists owing to the near proximity of the Wilcox ("Sabine") formation.

In the vicinity of Commerce, Hunt County, green sands occur bearing *Crassatellites subplanus* (Conrad)?, *Cardium* sp., and *Fusus* sp.

Above the glauconitic sands are beds of blue bituminous sandy shale and dark laminated clays, which are exposed only near Sulphur Bluff and 3 miles north of that place on the south side of South Fork, where a bluff 50 feet high is composed of black laminated clay with thin laminations of ferruginous sand grading downward into blue bituminous sandy shale. The blue sandy shales contain characteristic Cretaceous fossils which are best preserved in a hard, chalky ledge near the middle. The dark laminated clays and associated beds are thought to represent the horizon of the Arkadelphia clay, the larger part of which in this region is covered by the overlap of the Eocene.

Fossils.—Arenaceous and chalky beds 2 miles north of Enloe yielded the following fossils, as determined by Dr. T. W. Stanton, of the Survey:

Exogyra ponderosa Roemer.
Cucullæa sp.
Cinulia sp.
Mosasaurus, weathered centrum of a caudal vertebra and a fragmentary element of the skull.
Ostrea sp.
Inoceramus cripsi var. barabini Morton.
Baculites asper Morton?

From the chalk 1½ miles south of Ladonia in the southern part of Fannin County the following were obtained:

Gryphæa vesicularis Lamarck.
Gyrodes sp.
Avellana sp.
Baculites anceps Lamarck.
Cucullæa sp.
Anchura? sp.
Nautilus sp.

In a railway cut near Cooper the overlying marls yielded the following in considerable numbers:

Exogyra costata Say.
Inoceramus cripsi var. barabini Morton.
Trigonia.
Morea sp.
Gryphæa vesicularis Lamarck.

In the greensands 1½ miles west of Commerce the following were obtained:

Crassatellites subplanus (Conrad)?.
Cardium sp.
Fusus sp.

The following were obtained in the blue sandy shale at Sulphur Bluff, 3 miles north of the town of that name in Hopkins County:

Inoceramus proximus Tuomey.
Crassatellites subplanus (Conrad)?.
Lunatia sp.
Cucullæa tippana Conrad.
Turritella trilira Conrad.

Clays occurring one-half mile north of the town of Sulphur Bluff gave the following:

Ostrea sp.	Exogyra costata Say.
Veniella conradi Morton.	Anchura? sp.

All the above are considered by Dr. Stanton as belonging to the Navarro and Taylor formations, but there are no distinctive species that fix the exact horizon. In fact, as pointed out by Dr. Stanton, the paleontology of the Upper Cretaceous in northern Texas has not as yet received sufficient study to make fine discriminations practicable with only the small collections submitted.

TERTIARY SYSTEM.

EOCENE SERIES.

MAJOR DIVISIONS OF THE EOCENE.

The Eocene underlies all the area south of Sulphur Fork, as well as a small isolated area on the north side of that stream extending west from Texarkana south of New Boston nearly to the west boundary of Bowie County. In the eastern part of the area along Sulphur Fork the Eocene is covered by a wide belt of deposits of later age.

As developed in eastern Texas and the adjoining portions of Louisiana, the Eocene comprises the following subdivisions:

4. Jackson formation. Calcareous clays containing marine fossils in abundance.

3. Claiborne group. Lower portion: Fossiliferous, calcareous clay, argillaceous limestone, greensand, limonitic iron ore, etc., upper portion lignitiferous sands and clays.

2. Wilcox ("Sabine") formation. Lignitiferous sands and clays, with marine fossils in the seaward or southern portions.

1. Midway formation. Dark-colored calcareous clays and fossiliferous limestones.

MIDWAY FORMATION.

The Midway formation, called the "Basal" or "Wills Point clays" in the Texas reports,[1] consists of calcareous clays with more or less sand and closely resembles the underlying Cretaceous clays and marls. The chief differences noted are the more distinctly stratified structure of the Eocene beds with laminations of sand and the presence of concretionary masses of limestone, which toward the east in Arkansas appear to become regularly bedded limestones. Large quantities of gypsum are also found in the clays, but the lignitic material so prevalent in the overlying Wilcox is wanting. The surface exposure of the Midway is limited to the extreme western por-

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas. Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 47.

tion of the Eocene area and is marked by a belt of clay prairie lands extending with interruptions from Wills Point northward to Cumby and thence curving eastward past Ridgeway to South Fork.

The characteristic fossils of the formation are:

Enclimatoceras ulrichi White.
Ostrea crenulimarginata Gabb.
Ostrea pulaskansas Harris.
Volutilithes limopsis Conrad.

In common with other beds of the Eocene it contains:

Venericardia planicosta.
Pseudoliva vetusta.
Calyptraphorus velatus.
Turritella mortoni.[1]

The thickness of the Midway formation at Texarkana is about 214 feet and in Texas is from 260 to 300 feet.[2] The beds lie in a horizontal position, dipping slightly toward the southeast. These clays underlie a belt of prairie land with scattered belts and groves of hardwood timber, consisting mostly of post oak, black jack, and hickory.

WILCOX ("SABINE") FORMATION

The Midway formation grades upward into a series of siliceous and glauconitic sands, variously colored from white through yellow, red, and brown to black, interstratified with clays, which are generally dark blue or black. The sands that constitute the major part of the formation are laminated, thinly stratified, massive, and cross-bedded and are frequently interlaminated with clay. Many beds of lignite occur, varying in thickness from a few inches to several feet, and the sands and clays generally are impregnated with vegetal matter to such an extent that they burn white or buff on being exposed to heat. The sands contain more or less carbonate of lime, in places in sufficient amount to cement the sands into a calcareous sandstone or arenaceous limestone. Some of these indurated portions occur in somewhat even beds and some of them in concretionary masses of various sizes and shapes. When met in wells, these indurated masses are usually designated "rock" or "bowlders" by the driller.

According to previously published reports the Wilcox formation has an aggregate thickness of about 900 feet. In the well at Sulphur Springs (p. 61) the drill penetrated 1,317 feet of sand and clay that apparently represent the Wilcox and Midway formations, combined. Of this thickness 810 feet is assigned to the Wilcox.

[1] For a detailed discussion of the paleontology of the Midway formation see Harris, G. D., The Midway stage: Bull. Am. Paleontology, vol. 1, 1896, pp. 117-270.

[2] Penrose places the thickness at 250 to 300 feet (First Ann. Rept. Geol. Survey Texas, p. 23); and Kennedy (Third Ann. Rept. Geol. Survey Texas, 1892, p. 49) assigns them a thickness of 260 feet. In the Sulphur Springs well (p. 61) 324 feet of clays and sands have been referred to this formation.

CLAIBORNE GROUP.

The Claiborne group overlies the Wilcox and is said to contain "the most persistent and widely spread marine beds of the Coastal Plain." (See Veatch's map, fig. 2.) In northeastern Texas and northern Louisiana the group is divisible into a lower fossiliferous formation which has been called "Lower Claiborne," but for which Harris [1] has recently introduced the name St. Maurice formation, and an upper lignitiferous formation to which the name Cockfield has been given.

The upper portion of the Claiborne group consists of lignitiferous sands and clays, in which no marine fossils have been found except at the very top at Robertson Ferry, on Sabine River, and is known as the Cockfield formation. The bed exposed at Robertson Ferry containing marine fossils is included in the Cockfield formation.

The lower portion of the Claiborne is more calcareous, glauconitic, and clayey than the Wilcox and contains no lignitic matter. The thickness of the lower formation (St. Maurice) varies from 250 to 700 feet. The upper formation (Cockfield) consists of 400 to 500 feet of lignitiferous sands and clays, which are evidently of near-shore origin.

In southern Texas the "Lower Claiborne" was included by Kennedy in his "Marine beds" [2] and was subdivided into a lower division called Mount Selman and an upper division called Cook Mountain.[3] The "Marine beds" of Kennedy, however, included also a portion of the Wilcox which contains marine fossils.[4]

In southern Cass County and westward the Wilcox formation merges upward in places into brown and blue sands and clays, and glauconitic beds containing deposits of iron ore which may belong to the Claiborne.

Beds of this character occur in isolated areas and if of Claiborne age evidently represent outliers left in the general process of erosion. The fossils reported from these localities are not stratigraphically distinctive and the correlation with the Mount Selman formation is made chiefly on the presence of the iron ore and the general lithological character.

In the lower beds the iron exists in the form of carbonate of iron or clay ironstone, as scattered masses and nodules inclosed in the sand, in places coalescing into a bed continuous for several hundred yards. These layers are usually only a few inches in thickness and rusty from oxidation. In the southern part of Morris County, and

[1] Science, April 1, 1910, p. 502.
[2] Kennedy, William, Third Ann. Rept. Geol. Survey Texas, 1891, p. 52.
[3] Hayes, C. W., and Kennedy, William, Bull. U. S. Geol. Survey No. 212, 1903
[4] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 36.

in the southwestern part of Cass County, and extending thence west into Morris, Camp, Upshur, and the counties lying to the west, occur deposits of brown iron ore, lying horizontally near the tops of the hills, in some places at the surface and in others overlain by 1 foot to 30 feet of sand. The ore occurs in a variety of forms, botryoidal, stalactitic, mammillary masses, etc., but its characteristic form is that of loose nodules and geodes in a ferruginous sandy matrix or consolidated into irregular beds varying in thickness from 1 foot to 10 feet. The ores were termed "nodular or geode ores" by Penrose[1] who considers them to have been formed by the alteration of clay ironstone.

LATER TERTIARY DEPOSITS.

No marine deposits of Tertiary age later than Claiborne have been recognized in this part of northeastern Texas. Until near the close of the period the region appears to have been above sea level, or if temporarily depressed and subjected to sedimentation the deposits were subsequently removed by erosion. During Oligocene, Miocene, and early Pliocene times a general uplift caused the seacoast to recede toward the south to near the present coast. As a result of this elevation the region was subjected to more or less profound erosion and reduced to a level estimated by Veatch [2] to have been 500 to 700 feet above the present sea level.

In late Pliocene time there was deposited over the worn land surface a sheet of silts, sands, and gravels to which the name Lafayette was given by Hilgard.[3] In this part of northeastern Texas these deposits appear to have been removed by subsequent erosion. Redeposited remnants, however, occur as high-level terraces along the valleys and also as a thin gravel veneer over the rolling uplands.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

PORT HUDSON FORMATION.

During the long interval of erosion which succeeded the deposition of the Lafayette formation the gravels derived from that formation were concentrated in many places by stream action. Then came a slow subsidence, which converted the bottom lands into swamps and caused the deposition of the Port Hudson formation of sand, silts, and clays containing remains of animals and plants characteristic of

[1] Penrose, R. A. F., jr., First Ann. Rept. Geol. Survey Texas, 1890, pp. 76–81.

[2] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 44.

[3] Hilgard, E. W., Am. Geologist, vol. 8, 1891, p. 130. See also McGee, W J, Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, pp. 347–521. Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 44–46.

swamp conditions. In these old valley deposits the streams cut newer valleys of moderate extent, remnants of the Port Hudson now occurring as flat-topped terraces along the principal streams, at no great depth below the present flood plains. The distribution of these terrace deposits in northeastern Texas is shown approximately on Plate I (p. 16). In western Bowie and eastern Red River counties, as will be seen, the terraces belonging to the Red River and Sulphur Fork valleys, respectively, coalesce over the intervening areas. Moreover, over most of the area north of Sulphur Fork a mantle of gravel occurs with some patches of gravel which are possibly due to the augmentation of the rivers by glacial flood waters.

Along Red River, in Bowie and Red River counties, the height of the outer terrace is about 70 to 75 feet above the present flood plain; while about 35 or 40 feet below this another well-marked terrace was noted in places.

RECENT.

EROSION.

A slight elevation following the Port Hudson period of deposition caused a renewal of stream activity with the excavation of the present valleys and the formation of the present topography. The amount of erosion accomplished in this later period, however, is small as compared with that which was effected in late Tertiary and early Quaternary times. The chief changes consisted in the alluviation of river bottoms, the destruction of river banks, and the formation of cut-offs by the wandering of the rivers. In northeastern Texas the topographic and geologic changes have been slight.

NATURAL MOUNDS.

Scattered over the sandy areas in this and adjoining regions are innumerable small mounds varying from 20 to 100 feet in diameter and from 2 to 5 feet in height. They are especially well developed over the Port Hudson terrace plains, but occur also to some extent over the hill lands. In the Cretaceous area, outside the limits of the Port Hudson deposits, they are confined to the sandy belts representing the outcropping of the Blossom and Woodbine sands. In general, these mounds are rudely circular in outline, but in some localities they show a well-marked tendency toward a northeast-southwest elongation.

Mounds of similar character have a wide distribution and their origin has been a subject of much discussion. The problem is a perplexing one and remains as yet without satisfactory solution. Veatch, in a very complete review, groups the possible agencies of formation as human, animal, water erosion, eruptions, and wind.[1] Of the theories

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 55-59.

included under these heads he concludes that those relating to the dune and the ant hill are the best supported. In a later paper, Campbell [1] summarizes the various hypotheses as (1) human; (2) animal, such as ground squirrels, gophers, and prairie dogs' burrows; (3) ant hills; (4) water erosion; (5) chemical solution; (6) wind action; (7) physical or chemical segregation; (8) glacial action; (9) uprooted trees; (10) spring and gas vents; and (11) fish nests. In his discussion he disposes of all of these hypotheses except that which ascribes the origin to burrowing animals, and adds, "but whether the mounds are due to ants or to small rodents the writer is unable to say." He admits that many mounds may have been produced by wind action, and that probably many others of an entirely different origin may have been modified by the wind, but maintains that "the great number of natural mounds are far too symmetrical in profile and in plan to have been formed by wind-blown material."

In view of the wide distribution of natural mounds and their occurrence in regions widely separated, some doubt may reasonably be entertained as to all having been formed by the same agency. The writer's observations in northeastern Texas has led him to favor the theory which ascribes the mounds in this region to wind action. The fact that they are not uniformly circular but are at times elongated, and that the position of the longer axis is parallel with the direction of the prevailing winds, seems to offer some support to this theory. However, the time at the disposal of the writer did not allow full opportunity to determine satisfactorily the extent to which the linear arrangement prevails and further observations are needed to settle the matter.

STRUCTURE.

The warping of the old Jurassic land surface, which preceded and accompanied the deposition of later formations, gave the beds a gentle slope toward the Gulf, amounting, in Lamar County, to about 55 feet per mile.[2] This dip was estimated by taking the elevation by barometer of the base of the Goodland limestone north of Hugo, Okla. (475 feet above tide), and comparing it with the elevation as shown in the Paris well, 1,125 feet. The distance is about 29.1 miles, in which the rocks are carried down 1,600 feet, or about 55 feet per mile.

As to the attitude of the beds south of Sulphur Fork, no definite data are obtainable. If, however, this region has been affected by

[1] Campbell, M. R., Jour. Geology, vol. 14, 1906, pp. 708–717. Contains a fairly complete list of papers relating to the subject.

[2] Using the observed dips of the Goodland limestone, Taff estimated the dip at about 50 feet per mile, and predicted that the water-bearing Trinity sand would be found at Paris at a depth of 1,500 feet. In the well subsequently drilled there, however, these sands were reached at a depth of 1,635 feet, to which 91 feet must be added for the difference in elevation between the bench mark on the post-office building (601 feet) and the top of the well.

the Red River-Alabama Landing fault, as indicated by Hill [1] and Veatch,[2] the strata south of Sulphur Fork must lie nearly horizontal.

If, as suggested by Veatch, the Red River fault and the Alabama Landing fault constitute parts of the same general displacement, the fault line would occupy approximately the position of the Sulphur Fork, including North Fork. Owing to the covering of alluvial deposits, however, no traces of the existence of this fault can be observed except a disturbed condition of the Austin chalk beds noted by Hill [3] in the cut north of Pecan Gap station.

According to Hill and Veatch the displacement of this fault is about 600 feet, with the downthrow to the north. It is scarcely conceivable that a displacement of 600 feet could escape recognition in the vicinity of North Fork, as it would be sufficient to bring the Austin chalk to the surface in Delta County. The writer was at first inclined to think that the chalk near Enloe might be the Austin brought up by faulting, but his further study of the stratigraphic relations and faunal contents of these beds did not support this conclusion. It seems probable, therefore, that if any displacement has occurred here its extent is much less than 600 feet.

UNDERGROUND WATER.

SOURCE.

All underground water is derived from rainfall. A considerable part of the rainfall runs off the surface and is carried away by streams; a part is removed by evaporation or consumed by living organisms and in chemical work; and the remainder sinks into the soil and unites with the underground waters, to reappear in part as springs at more or less distant points.

The proportion of the rainfall disposed of by evaporation and run-off and by percolation and absorption into the rocks, varies with climatic, topographic, geologic, and other conditions. The portion which sinks into the ground furnishes the entire supply for both deep and shallow wells, and it is this alone that need be considered so far as underground waters are concerned.

The percentage of the rainfall which sinks into the earth is determined by (1) the character of the rains, whether slow and steady or of a torrential nature; (2) the topography of the country, whether flat or with many steep slopes; (3) the character and amount of vegetation covering the surface; and (4) the porosity of the soil and the physical character and state of saturation of the underlying beds.[4] The surface of the zone of saturation varies with climatic conditions,

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, p. 384.
[2] Veatch, A. C., op. cit., pp. 68–69.
[3] Hill, R. T., op. cit., p. 342.
[4] Veatch, A. C., op. cit., p. 70.

rising in periods of long continued rains and sinking during periods of drouth. In regions of excessive rainfall and limited evaporation its upper limit usually coincides with the surface, whereas in arid regions it may be several hundred feet below the surface. Moreover, the upper line or limit of saturation—the water table—conforms in a general way to the surface, rising somewhat higher under elevations than under depressions.

AVAILABILITY OF UNDERGROUND WATER.

The availability of the water that sinks into the soil depends on (1) the adequacy of the supply and the quality of the water contained in the rock formations, and (2) the depth at which it may be encountered and the height to which it will rise in wells. The permanency of the supply depends on the capacity of the rocks for absorbing and transmitting water, and the quality of the soluble minerals contained in the beds through which it passes. The feasibility of obtaining water at any locality depends on the position and elevation of the rock strata and the structural relations which control the arrangement of the rock masses. It is evident, therefore, that the controlling factors in the utilization of underground water are the composition of the rocks and their arrangement in sheets and masses, or, in other words, the geologic structure.

CAPACITY OF ROCKS FOR IMBIBING WATER.

The capacity of rocks to imbibe moisture varies with their physical structure. Most of the water in rocks occurs in pores and interstices, the larger part of the world's well-water supply being derived from saturated porous beds, only a small part of it being obtained from caverns or large cavities. Practically all rocks, however compact they may appear to the eye, have interstices and small cavities in which water may be stored. The degree of porosity of rocks, however, differs greatly in different rocks, being highest in open-textured loose sands, sandstones, gravels, and chalks, all of which have great capacity for imbibing water, and lowest in close-textured clays, slates, marbles, and granites, which have very small capacity for absorbing and transmitting water. Some rocks, however, such as granite, which in their original condition are almost impervious, become water bearing through the development of fractures and crevices.

The capacity of rocks for transmitting water is different from their capacity for imbibition. In certain fine-grained rocks the pore spaces are so small that they will not readily transmit water. Hence rocks like chalk or brick, which absorb water freely, transmit it slowly, whereas others with no greater total pore space transmit it readily. Sandstones, for instance, vary greatly in texture and consequently in their capacity for carrying water.

ARTESIAN WATERS DEFINED.

Underground waters which under the influence of hydrostatic pressure tend to rise to the level of the water surface at the highest point from which the pressure is transmitted are known as artesian waters. Hence an artesian well is any well in which the water rises under artesian pressure. If the water rises to the surface the well is known as a flowing artesian well; if the water fails to rise to the surface it is known as a nonflowing artesian well. An artesian system is any combination of geologic structural features—such as basins, planes, joints, or faults—in which waters are confined under artesian pressure and will rise if an outlet is afforded by a well or other perforation. An artesian basin is a basin of porous-bedded rock in which, as a result of synclinal structure, the water is confined under artesian pressure. An artesian slope is a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction to its downward passage by the pinching out of porous beds, by a change in character from pervious to impervious, by internal friction, or by dikes or other obstructions. An artesian area is an area underlain by water under artesian pressure.

CONDITIONS THAT DETERMINE ARTESIAN WELLS.

The distribution of underground water depends on the arrangement of the rocks in sheets and masses. If the strata are horizontal they constitute storage systems in which the water is under little or no artesian pressure and will escape only laterally as seepage springs where the beds are cut by valleys of erosion. If the water bearing beds are inclined and are included between impervious sheets, the water absorbed over the outcropping area will sink under the influence of gravity and if reached by a well at any point beyond the limit of its outcrop will tend to rise therein to the level of complete saturation.

The water pressure and, therefore, the height to which water will rise depend on several conditions: (1) On the elevation of the ground-water table at the outcrop or source, which in turn depends on the uneven elevation and surface conformation of the catchment area; (2) on the loss by friction in transmission, a factor which depends on the size of the spaces between the grains and is not by any means uniform even in the most even-textured beds; and (3) on the loss by leakage resulting from increases in porosity of the inclosing beds from faults, joints, and other natural breaks, and, locally, from the multiplication of wells within a restricted area. Hence the level to which water will rise in wells is always somewhat lower than the lowest point of the outcrop of the containing beds and becomes lower and lower with increasing distance from the catchment area.

The factors controlling the occurrence of flowing wells may be briefly stated as follows: (1) There should be relatively porous beds suitably situated to collect and transmit the water; (2) the water-bearing beds should be inclosed between other relatively impervious layers to confine the water; and (3) the level of the ground-water table at the source should be enough higher than the surface at the point where the well is located to compensate for the loss of head due to resistance and leakage. As these conditions vary from point to point it is evident that both flowing and nonflowing artesian wells

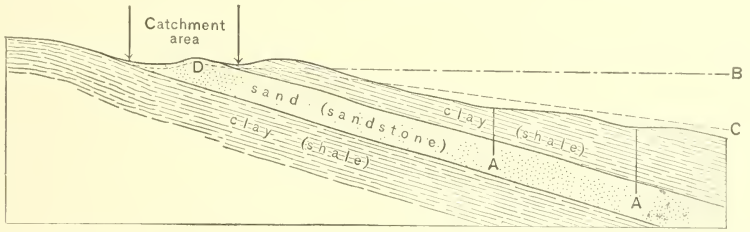


FIGURE 3.—Diagram showing the common arrangement of factors producing artesian wells. *A*, artesian wells; *B*, head of water if there were no loss by resistance or leakage; *C*, actual head of hydraulic gradient; *D*, ground-water table at outcrop.

may occur within the same artesian area. The accompanying diagram (fig. 3) illustrates the most common arrangement of factors producing artesian wells.

ARTESIAN WATERS IN NORTHEASTERN TEXAS.

GENERAL GEOLOGIC RELATIONS OF THE WATER-BEARING BEDS.

Within the area here considered the known water horizons occur in the Cretaceous and Tertiary and may be represented as follows:

Water-bearing formations in northeastern Texas.

System.	Formation.	Character.
Tertiary (Eocene).	Wilcox ("Sabine") formation.	Sands and clays. Certain beds water bearing. No correlation possible.
	Midway formation.	Mostly clays, some thin beds of limestone in places. No water. Some sandy beds slightly water bearing.
Upper Cretaceous (Gulf series).	Navarro formation and Taylor marl.	Clay marls, not water bearing. Glaueonitic sands. An important water horizon in Arkansas; of doubtful utility in Texas.
		Clay and chalk marls in places sandy. Near the base a bed of sand appears to be water bearing, but it has not been developed.
	Austin group.	Chalk (Annona) and chalk marl (Brownstown). Not available as a source of water. Contains hard water where porous.
	Eagle Ford clay.	Blossom sand member. Water bearing. Clays. No water, or limited supplies of highly mineralized water.
	Woodbine sand.	Sands and shales. The sands are usually water bearing. Several water horizons.

Water-bearing formations in northeastern Texas—Continued.

System.	Formation.	Character.
	Washita group.	Impure limestones and usually nonwater-bearing marls; 35 feet of sand [a] with water occurring in the Paris well.
Lower Cretaceous (Comanche series).	Fredericksburg group (Goodland limestone).	Massive white limestone. No water.
	Trinity sand.	Sands and clays with thin beds of limestone. Important water horizon in Texas; becomes of less importance eastward.

[a] According to Mr. J. A. Porter (p. 46), the seventh water horizon occurred under a limestone "caprock" at 1,635 feet. The sandstone is evidently the one mentioned by Hill (p. 46) as occurring at 1,650–1,685 feet, but Hill does not state that it is water bearing. The discrepancy as to the lower portion of the Paris record is not easily reconcilable, there being no reliable data available for that part of the hole.

CRETACEOUS SYSTEM.

TRINITY SAND.

The Trinity sand is an important water-bearing horizon, supplying a large number of wells in central Texas, where it is divisible into several formations, known as the Trinity group. In the main the beds consist of fine, clean, white sand pressed compactly together and popularly known as "packsand." The group includes some calcareous beds, which increase in thickness toward the southern part of the State, and are there known as the Glen Rose limestone.

The outcrop of the Trinity sand occurs in Oklahoma several miles north of Red River. This catchment area constitutes a belt from 5 to 10 miles in width, extending nearly due east into Arkansas. From this line of exposure the southward dip of the beds carries them beneath all this part of northeastern Texas to depths proportionate to the distance from the outcrop. The only available record of the depth to the Trinity sand in northeastern Texas is that of the well at Paris (p. 45), where it was reached at about 1,735 feet. From this record and from the depth of the sands as shown by a well at Hugo the dip of the formations is estimated at about 56 feet per mile.

Sands being near-shore formations they gradually give place seaward to contemporaneous clays and limestones formed in deeper and quieter waters. This change consists both in an increase in the argillaceous and calcareous constituents of the rocks and in a wedging out of the sands. This imbrication of the strata is shown in the ideal diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas given by Taff [1] (fig. 4, p. 39).

Water falling upon the outcrop of the Trinity sand or carried over it by rivers sinks into it readily, and for a certain distance from the outcrop these sands furnish an abundant supply of water of excellent quality. Farther away, however, the water becomes affected by

[1] Taff, J. A., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 697.

mineral constituents taken up in its underground passage, and is likely to be too highly mineralized for ordinary use.

The conditions which control the height to which water will rise in wells has been explained (p. 37). Within the main zone of saturation water pressures in a formation are likely to be unequal, owing to differences in the coarseness of the strata, leakage through springs, and local irregularities in the additions supplied by rainfall. Hence there is a gradual decline in the pressure head with increase of distance from the line of outcrop. In the absence of accurate relief maps of northeastern Texas any statement of the areas in which flowing wells may be expected from any particular horizon can be approximate only. At its outcrop north of Hugo the Trinity sand stands about 500 feet above sea level. The elevation of the top of the well at Paris is 510 feet. Water from the Trinity would therefore lack 10 feet of rising to the top even if it sustained no loss of pressure. The amount of such loss is unknown, but assuming it to be 30 or 40 feet the water from the Trinity sand would lack 40 or 50 feet of reaching the surface at Paris. The area in which flowing wells may be expected from the Trinity sand in the vicinity of Paris or at points equally distant from the outcrop must therefore have an altitude of less than 450 or 460 feet above sea level, hence these wells would be confined to the valley of Red River.

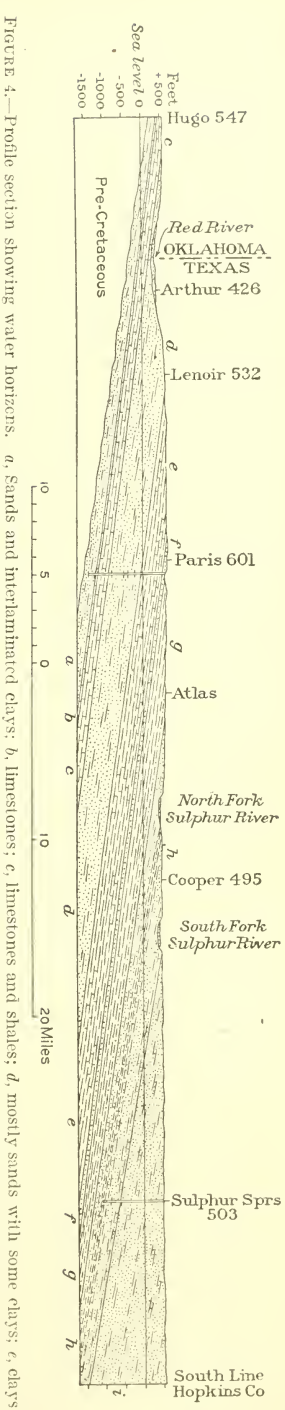


FIGURE 4.—Profile section showing water horizons. *a*, Sands and interlaminated clays; *b*, limestones; *c*, limestones and shales; *d*, mostly sands with some clays; *e*, clays with thin limestones; *f*, Blossom sand member of Eagle Ford clay; *g*, Annona chalk and Brownstown marl; *h*, sandy and clay marl, some chalk; *i*, sands, clays, and sandstones.

WASHITA GROUP.

The Washita group has not hitherto been recognized as including water-bearing beds. Its mention here is based on the somewhat doubtful assignment to it of the seventh water horizon in the

Paris well (p. 45). Even if the seventh horizon belongs to the Washita, some doubt exists as to whether the water came from that level (sandstone No. 24 of the section) or from some lower horizon. Hill in his section (p. 46) gives a sandstone at 1,650 to 1,685 feet, but does not credit it with having water. Mr. Porter's log shows the seventh water horizon at 1,635 feet just below a limestone, a depth very close to that of the bed (24) shown in Hill's section.

A point in favor of assigning the bed to the Washita group is the statement of Mr. Porter that the water from it rose to within 2 feet of the surface. The evidence available does not support the view that water from the Trinity would rise so high. The Washita, on the other hand, outcrops in the vicinity of Hugo at a higher level than the Trinity and can reasonably be expected to furnish flowing wells at a level of 500 to 510 feet in Lamar County. In general the Washita group consists of shales and limestones, but it contains some arenaceous beds in the upper part (Denison formation; the Pawpaw beds of Hill), and these may contain water in some places.

Flowing wells may be expected from the Washita group, if water bearing, along the south side of Red River in Lamar County at altitudes of 500 feet and under. Toward the east the pressure evidently declines because of the gradual lowering of the surface of the outcropping beds in the territory. The area in which flowing wells may be had from this horizon is probably confined to Lamar County and the extreme northern part of Red River County.

WOODBINE SAND.

The Woodbine formation consists of alternations of sands, sandstones, clays, and marls, commonly lignitiferous and glauconitic and containing iron pyrite. The character of the waters also indicates that some of the beds contain more or less iron and salt. The lower portion of the formation, called by Taff and Hill the Dexter sand, has layers of considerable thickness, which are free from mineral matter and rather porous. The water from this horizon (sixth) in the Paris well (p. 45) rose to within 6 feet of the surface. Its character was not adequately tested, however, as it was allowed to mingle with the more mineralized waters from the higher beds. The upper portion of the Woodbine includes several beds of sand which are water bearing, but they contain quantities of vegetable and animal remains which, together with soluble salts, so impregnate the water as to render it useless.

North of Paris Red River flows upon the outcrop of the Woodbine formation, the sands appearing on both sides of the river in the bluffs bordering the alluvial bottoms. On the south side of the river the sands outcrop in a belt several miles wide, extending through the northern part of Fannin, Lamar, and Red River counties, except where covered by Recent alluvial formations.

EAGLE FORD CLAY.

Lower clays.—The lower portion of the Eagle Ford consists of blue marly clays containing hard concretions, with occasional layers of sandy shale. The sandy constituents increase downward and the formation gradually passes into the Woodbine sand below. This part of the formation is for the most part dry, but in places it contains small quantities of water, which, however, is too highly charged with deleterious substances to be used.

Blossom sand member.—The upper 50 to 80 feet of the Eagle Ford clay consists of glauconitic sands irregularly interlaminated with clays. On exposure the sands become red from the oxidation of the contained iron. These sands outcrop in a narrow band from 1 mile to 2 miles wide, extending east and west across Red River, Lamar, and Fannin counties and adjoining on the south the Eagle Ford black prairies or clay belt. The towns of Blossom, Paris, and Detroit are located on the outcrop of these sands, the first named giving the name to the beds. The shallow wells along the outcrop commonly range from 25 to 75 feet in depth and yield an abundant supply of soft water, which in some wells is of good quality, but which in most is impregnated with variable amounts of mineral matter. The quality of the water from the embedded portion of this sand seems to be good, as shown by the Clarksville waterworks wells, which derive their supply from it.

The sands appear to have a thickness of more than 60 feet generally, but only a small part of the member is water bearing—a fact that must be taken into account in sinking wells to this horizon.

AUSTIN GROUP.

The Austin group consists chiefly of chalks (Annona chalk) and chalk marls (Brownstown marl) and is in the main destitute of water. In places, however, the beds are somewhat porous and may then furnish limited supplies of very hard water.

NAVARRO FORMATION AND TAYLOR MARL.

The Navarro formation and Taylor marl consist of clay and sandy marl, with some sand and chalk. Near the base is a bed of chalk, which outcrops near Enloe and southwestward in the vicinity of Pecan Gap and Ladonia. Underneath the chalk is a soft yellow sand, which outcrops at Ladonia. The thickness of this sand is nowhere clearly shown, but probably does not exceed 50 or 60 feet. At Pecan Gap 30 feet of sand underlie the chalk, the base of the sand not being exposed. Portions of the sand become notably calcareous, with occasional thin chalky layers. Downward the sands grade into sandy yellow clay containing many *Exogyra*.

The outcrop of this sand constitutes a narrow band through the northern part of Delta County and southwestward in Hunt County through Wolf City. Its water-bearing character has not been tested underground, but its character and outcrop indicate that it may constitute a source of supply in a belt a few miles wide along its south border. As the catchment area is not extensive it is not likely to prove a very important horizon and will probably not be available for wells except in a comparatively small area.

In Arkansas the Nacatoch sand (see p. 25) constitutes an extensively exploited water horizon. At Texarkana it contains no less than eight water-bearing beds, two of which (at 1,020 and 1,174 feet, respectively) showed strong pressure. In Texas these beds show a diminution in their porous sandy character, and though still water bearing to some extent are of less importance in this respect than in southern Arkansas. In southern Delta County a narrow belt of glauconitic sandy shales and sands, which apparently represent this formation, outcrops along the north side of South Fork and just west of Commerce. The outcrops are meager, however, and the character and relations of the beds are not clearly shown. In a well 100 feet deep at Sulphur Bluff these sands were reached at 30 feet and were found to contain water, which, however, was not used. The overlap of the Eocene south of Sulphur Fork has covered the higher portions of the Cretaceous and nothing can be said of these beds here.

TERTIARY SYSTEM.

WILCOX ("SABINE") FORMATION.

The Wilcox ("Sabine") formation in this region consists of ferruginous and lignitiferous sands, ferruginous sandstones, and blue and brown clays, with one or more beds of lignite and local beds of iron ore. The formation is generally water bearing, but as its character changes from place to place no definite correlation can be made between the water sands in different localities. Owing to the lenticular character of the bedding it is probable that the water sands are of local extent only and occur in different positions within the formation.

Underground-water conditions in the Wilcox formation differ materially from those in the Cretaceous. In the Cretaceous the sandy beds lie between more impervious strata, thus permitting the water to enter only at the outcrop. In the Tertiary (Eocene) no such definite relationship exists between the clays and sands, there being no well-defined persistent clay layers. The whole series being predominantly sandy the water is relatively free to penetrate the beds at any point. Hence the head in any case is dependent not on the height of the ground water table at the outcrop of the horizon tapped, but on its height near the well.[1]

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 81–82.

From the evidence supplied by the Sulphur Springs well (see p. 61) it would appear that below a depth of 50 feet in that vicinity the beds of the Wilcox are largely barren. At Mount Vernon, however, 20 to 25 miles farther east and about 25 feet lower, an abundant supply of water is found at about 400 feet. At Mount Pleasant no water was found below the surface sands to a depth of 300 feet, but at Pittsburg, 12 miles south, 33 feet of water sand occurs at 151 to 184 feet. At Daingerfield, 15 miles east of Pittsburg and at about the same level (400 feet above tide), the gin well is apparently supplied from the same bed at a depth of 186 feet, the water rising to within 20 feet of the surface. This sand probably has its outcrop somewhere between Mount Pleasant and Pittsburg. At Jefferson a well whose top is 196 feet above tide obtains water at a depth of 830 feet.[1]

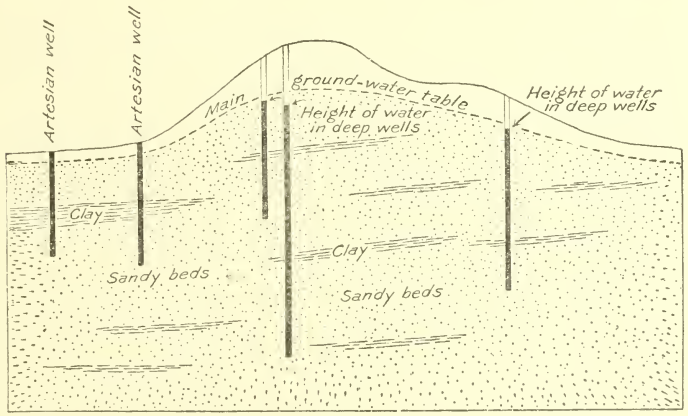


FIGURE 5.—Diagram showing water conditions in the lower Eocene strata in northwestern Louisiana and southern Arkansas. The beds are predominantly sandy, with irregular discontinuous clay masses; water is relatively free to pass to any part of the beds, and the hydraulic head depends on the local position of the ground-water table rather than on its position at the outcrop of the water-bearing beds.

At Hawkins, in the valley of the Sabine River, in Wood County, a flowing well is reported at a depth of 200 feet. The elevation of the town is 394 feet.

In general the water-bearing character of the Wilcox formation beds is controlled by the variation in the porosity of the beds from place to place, and hence the successful development of a well depends on finding a bed coarse enough to act as a natural horizontal strainer and so aid in removing the water in the adjoining finer beds. Although the sand beds vary greatly in physical character and thickness within short distances, there are, nevertheless, certain beds in which the chances of developing a satisfactory well are greater than in others. Of these the most important are located toward the top of the formation and are represented in the Pittsburg and Daingerfield wells.

[1] The authority for the depth of this well is Mr. J. M. De Ware, of Jefferson. In Hill's report (Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 414) the depth of this well is given as 802 feet.

SURFICIAL SANDS AND GRAVELS.

The irregular deposits of sand and gravel of late Tertiary and Quaternary age, which in places overlie the older Tertiary and Cretaceous beds, are of varying value as water carriers. Wells in these beds situated on the hills are likely to be of some slight local importance. In the larger river valleys, however, they may yield large supplies.

REVIEW BY COUNTIES.

LAMAR COUNTY.

Geographic relations.—Lamar County adjoins Red River, in the extreme northwestern part of the area included in this report. It comprises an area of 903 square miles and in 1910 had a population of 46,544. Its county seat and chief town is Paris, with a population of 11,269. The county is traversed by the Texas & Pacific, St. Louis & Southwestern, and Texas Midland railways.

The drainage of the county is divided about equally between Red River and North Fork of Sulphur River, the divide between the two systems passing east and west across the county near the middle. The general slope is toward the southeast. The surface is rolling, without pronounced relief, the drainage ways being but moderately incised below the general plain level.

Geology.—The south half of the county is underlain by light to dark-brown and jet-black clay or clay loam designated Houston clay and Houston black clay by the Bureau of Soils; these, constituting what is locally known as black waxy land, are residual soils derived from the weathering of the clay and chalk marls of the Austin group. Northward from Paris the gray sandy clay loam derived from the Eagle Ford clay extends to the vicinity of Lenoir, from which point north to the river a strip of sandy soil 2 to 10 miles wide represents the outcrop of the Woodbine sand.

Lamar County lies upon the outcrop of the lower half of the upper Cretaceous, comprising within its boundaries the Woodbine, Eagle Ford, Brownstown, and Annona formations and the Taylor marl, which outcrop in successive belts extending east and west across the county. North of the Brownstown area is a strip of sandy soil 1 to 2 miles wide which represents the outcrop of the upper arenaceous layers of the Eagle Ford, to which in this report the name Blossom sand member is given. The approximate distribution of the outcrops of the different formations will be seen on the map (Pl. I). Within the area of the Eagle Ford clay a number of isolated patches or outliers of overlying formations have not been entirely removed by erosion. No attempt has been made to map these areas. The strata have a dip of 50 to 60 feet per mile toward the south-southeast.

Water resources.—Throughout the clay-land area cisterns and tanks constitute practically the sole source of water supply in Lamar County. Paris derives its supply from a rain reservoir about 6 miles west of town. In 1896 the city made a determined effort to develop an underground supply, but without satisfactory results. Shallow wells and springs are common in the area of the Woodbine sand, the supply for the most part being ample and the quality good.

Although the Trinity sand underlies the whole county (see fig. 4) only in the northern part is it near enough to the surface to be practically available. Its catchment area northward in Oklahoma is lower than the surface of most of Lamar County, hence flowing wells from this horizon can be expected only in the low-lying districts, notably along the valley of Red River.

A well put down by S. J. Wright on the banks of Red River opposite the mouth of Kiamichi River is reported to have found an abundant flow of water in these beds at a depth of 301 feet, the water having sufficient force to rise to a considerable height above the surface. Owing to the caving of the well, the drill was lost and the well abandoned.

The Woodbine sand outcrops in the northern part of the county and over its area the ground-water table can be reached by wells at depths of 20 to 50 feet. Southward from the outcrop the sands lie at constantly increasing depths. At Paris the first water sand of this formation was found at 600 feet.

A detailed section of the Paris well has been kindly furnished by Mr. John A. Porter, the superintendent. The boring, which was made by the city waterworks, is located 2½ miles east of the city square. The elevation is 510 feet above tide (91 feet lower than the United States Geological Survey bench mark on the Government building, which reads 601 feet). The well was completed December 19, 1906.

Record of the Paris well.

Formation.[a]		No.	Character.	Thickness.	Depth.
				Feet.	*Feet.*
Eagle Ford clay.	Blossom sand member.	1	Sand with thin soil on top	60	60
		2	"Packsand;" first water	20	80
		3	Blue marl	100	180
		4	Blue marl with trace of sand at top	320	500
		5	Marl of lighter color; second water at 570; rose to within 110 feet of surface.	100	600
Woodbine sand.		6	Gray sandrock	50	650
		7	Marl	125	775
		8	Sandrock; third water; rose to within 100 feet of the surface	8	783
		9	Marl	175	958
		10	Gray sandrock; fourth water; rose to 75 feet from surface	25	983
		11	Marl	66	1,049
		12	Gray sandrock; fifth water; rose to 30 feet from surface	31	1,080
		13	Marl	33	1,113

[a] Identifications by the writer.

Record of the Paris well—Continued.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Woodbine sand.	14	Red sandrock	52	1,165
	15	Sandrock and clay	6	1,171
	16	Sandrock with indications of lime; sand almost white	105	1,276
	17	Unrecorded; "was drilled while sand bucket was being drilled out."	39	1,315
	18	Marly lime and sand } Sixth water; rose to within 6 feet of the surface.	33	1,348
	19	Sandrock }	39	1,387
	20	Loose sand }	25	1,412
	21	Gravel }	8	1,420
Washita group and Trinity sand.	22	Sand, followed in succession by shell rock (8 to 10 inches) and alternating layers of limestone and marl darker below.	130	1,550
	23	Unrecorded; said to penetrate limestone at the bottom	85	1,635
	24	Unrecorded; sand at top; seventh water, which rose to within 2 feet of the surface.	360	1,965

The above record to a depth of 1,550 feet (Nos. 1 to 22) corresponds with that published by Hill.[1] The remaining portion of Hill's record, which stops at 1,726 feet, is as follows:

Record of lower part of Paris well (by Hill).

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Washita group.	23	Unrecorded	100	1,650
	24	Grayish friable sandstone	35	1,685
	25	Impure argillaceous limestone with fossils	15	1,700
	26	Impure limestone with *Gryphæa washitaensis*	10	1,710
Goodland limestone.	27	White limestone resembling Goodland limestone	15	1,725
	28	Hard arenaceous limestone with *Pecten* and *Anomia*	+1	1,726

According to Porter, water was found in sand at 1,635 feet. This is evidently the sand noted in Hill's section at 1,650 to 1,685 feet (No. 24). Hill makes no mention of water at this horizon. From the greater detail given by Hill from 1,550 to 1,726 feet it is probable he had before him the drillings from the well. Later the well was extended to 1,965 feet, but no record is available for this portion. The Trinity must have been reached at about 1,735 feet, but nothing is known of its water-bearing character.

The Paris well is located on the outcrop of the Blossom sand member, which constitutes the upper part of the Eagle Ford clay, in which five small water reservoirs were encountered within the first 100 feet. In the Woodbine, aggregating about 800 feet in thickness, are six beds of sand, five of which are water bearing. The first yielded at 570 feet a strong flow of briny water, which rose to within 110 feet of the surface; it may represent a water sand within No. 5, not otherwise noted. The second (No. 8) also yielded salty water,

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 629.

which rose 10 feet higher than that from No. 5. The third at 958 feet yielded water that rose to within 75 feet of the surface, and the fourth at 1,049 feet water that rose to within 30 feet of the surface. All of the waters were briny and unfit for use. In the fifth sand (No. 19) a strong flow was reached at 1,350 feet and rose to within 6 feet of the surface. The quality of this water is unknown, as the waters from above were allowed to mingle with it. This sand is inferred to be the basement reservoir of the Woodbine, which is so prolific of wells in regions to the southward. The next water, the seventh, according to Porter, came from beneath a bed of limestone at 1,635 feet and rose to within 2 feet of the top. The failure to exclude the higher waters throws doubt on the character of those from the two lowest flows. The height to which the water rises indicates that flowing wells may be obtained from these horizons in Lamar County at localities having elevations under 500 feet.

In the area of outcrop of the Blossom sand member water is found in shallow wells at depths ranging from 15 to 50 feet. The water from many of these wells is strongly mineralized, but a notable difference is manifested by the waters of wells which are near together. The well of the Texas Midland Railway at Paris is located in these sands at an altitude of about 566 feet. The following record, which has been published by Hill,[1] was supplied by the president of the company, E. H. R. Green.

Well of the Texas Midland Railway, Paris, Lamar County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Residual soil grading into sand and clay	18	18
2	Black sand, water bearing, yielding 1,200 gallons per day	15	33
3	Hard barren pack sand	12	45
4	Top portion of barren joint clays	28	73

At Blossom, a station on the Texas & Pacific Railway 12 miles east of Paris, a number of wells have been sunk to depths of 15 to 40 feet. W. E. Moore's well, located near the edge of the Black Prairie, in the south part of the town, gave the following record:

Well of W. E. Moore, Blossom, Tex.

No.	Character.	Thickness.	Depth.
		Ft. in.	*Ft. n.*
1	Top soil and clay	6	6
2	Sand and clay mixed	25	31
3	Red sand rock	10	31 10
4	Dark sand	4	35 10
5	Dark clay or slate	110	145 10

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 631.

Water, doubtless coming from the sand of No. 2, rose in this well to within 30 feet of the surface. The water is not used.

A well 117 feet deep put down near the depot several years ago yields a small supply of mineralized water which is regarded locally as having valuable medicinal properties. The only soft-water well in town is that of John Carter, on the north side of the village. It is about 30 feet deep. (See analyses of water of the Blossom wells, p. 74.)

In the south part of the county the Blossom sand member apparently underlies all the black-land area and can be reached at gradually increasing depths up to 1,400 or 1,500 feet. Wells located on the Annona chalk belt will reach the sands at depths of from 300 to 600 feet. The water-bearing character of these sands underground in Lamar County has not been tested and their availability is largely a matter of conjecture. At Clarksville, in Red River County, however, they yield an ample supply of good water for the use of the city and it is quite probable tnat similar supplies may be found in them in Lamar County. In the absence of well records no definite statement can be made as to the height to which water from the Blossom sand member will rise in the county. At Clarksville the wells have an elevation of about 450 feet and the water rises to within 55 feet of the top. At their outcrop 4 miles north of town t e sands have an elevation of about 400 feet. Westward there is a rise in the surface outcrop with a corresponding rise in the water table to about 550 feet at Paris. From this it will appear that flowing wells can not be expected from the Blossom sand member in Lamar County at elevations greater than 500 to 525 feet.

DELTA COUNTY.

Geographic relations.—Delta County borders Lamar County on the south and occupies the triangular-shaped area between North and South forks of Sulphur River. It has an area of 266 square miles, with a population of 14,566; the county seat is Cooper. The county is traversed from northeast to southwest by the Texas Midland Railroad and is intersected for short distances in the northwest and southwest corners by the Gulf, Colorado & Santa Fe and St. Louis & Southwestern railroads, respectively.

The county is an eastward-dipping plain, grading from the rolling black prairie on the north and west to an almost flat surface on the east. Elevations are: Enloe, 495; Cooper, 495; Klondike, 478; and Ben Franklin, 465 feet, above sea level. It is drained entirely by North and South forks of Sulphur, the larger part going to the latter on account of the general slope. None of the drainage ways are conspicuous.

Geology.—The county is situated on the outcrop of the uppermost beds of the Upper Cretaceous as represented in Texas, South Fork following approximately the boundary between the Cretaceous and the overlying Eocene Tertiary. A single small area of Cretaceous in the form of an inlier occurs south of South Fork at Sulphur Bluff in northeast Hopkins County. Outside a narrow belt bordering South Fork the soils of Delta County are of the black waxy type characteristic of the black-prairie region of Texas.

Water resources.—In the black-land areas the water for domestic use is derived almost entirely from cisterns and tanks. In the rather small sandy areas both wells and cisterns are in use. A boring made by Mr. E. H. Bond 3 miles southwest of Cooper to a depth of 263 feet was wholly in clay marl. The section is as follows:

Record of E. H. Bond's well 3 miles southwest of Cooper, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Black soil	5	5
2	Yellow sandy clay marl	45	50
3	Blue clay marl	213	263

No water was found except a "slow seep" from No. 2. This is the source from which the water of the shallow wells is derived, but the water is hard and brackish and little used except for stock.

In the sandy areas in the south part of the county the wells range in depth from 10 to 100 feet. The water is reported to be fairly good and the supply ample, but cisterns are coming into general use. Throughout the county rain reservoirs and tanks are relied upon mainly for stock supplies.

No effort has been made to exploit the underground waters of Delta County. A study of the geology shows that although the Trinity and Woodbine reservoirs undoubtedly extend beneath the county, they are at too great depth to be available even if they were likely to furnish a desirable quality of water, which is improbable. The estimated depth of the Trinity at Cooper is about 3,000 feet. The depth to the first water sands of the Woodbine is 1,800 to 2,000 feet and to the lowest, the only one concerning whose quality doubt exists, is 800 to 900 feet deeper. The Blossom sand member can be reached at a probable depth of from 1,200 to 1,300 feet. In the absence of any test well in the region, however, no safe prediction can be made as to its availability as a source of water supply so far from the outcrop.

The only other apparent source of underground water over the larger portion of the county is the sand bed which outcrops along the south side of North Fork. This sand evidently extends beneath the larger part of the county. From its outcrop it appears to dip south

by southeast, and can be reached at increasing depths according to the elevation of the surface and the distance from the outcrop. At Commerce, Hunt County, it lies at a depth of 600 feet and, as shown by the Midland Railway well (see below), is water bearing. At Cooper the sand is estimated to lie at a depth of 500 to 600 feet. As the surface is 30 to 50 feet higher at Cooper than at the outcrop of the sand, flowing wells could not be expected, but the water would probably rise to within 50 feet of the top of the well. The width of the outcrop or catchment area of the sand is from 1 to 2 miles.

The upper sands (Nacatoch?) outcrop in a narrow belt along the south side of the county through Klondike and to the north of Commerce just over the line in Hunt County. These sands would be available for wells only in a restricted area bordering South Fork. At Horton, 4 miles south of Klondike, these sands were reached at 315 feet:

Record of well at Horton, Delta County, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Surface sand	30	30
2	Blue "slate"	60	90
3	Black clay	225	315
4	Water sand	(?)	.....

At Commerce, Hunt County, which is located at about the same geologic horizon, the same sands occur at a depth of 370 to 385 feet, according to the somewhat imperfect records available.

Record of Capt. Ander's well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Soil	10	10
2	Joint clay	30	40
3	Blue shale	330	370
4	Water sand beneath a hard ledge	.....	.....

Record of Texas Midland Railroad well; elevation, 548 feet, approximate.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Blue and yellow clay	20	20
2	Thin stratum of flowing sand with 6 inches of limestone	.....	.....
3	Blue sandy shale	365	385
4	White water sand	4	389
5	Hard limestone	4	393
6	Blue sandy shale	195	588
7	Hard sandstone	6	594
8	White sand with water	6	600
9	Blue sandy shale	55	655
10	Unrecorded	25	685

The depth of this well is given on the authority of Mr. L. W. Wells, assistant to the general manager of the Texas Midland Railroad, who states that the upper horizon has been cased off. The upper sands (No. 4) apparently represent the Nacatoch. The lower sands (No. 8) apparently represent the sands which outcrop near Ladonia. The statement by Hill[1] that a well 2,390 feet deep had been put down by H. G. Johnston at Commerce is an error, as Mr. Johnston writes that he has never put down a well at Commerce.

RED RIVER COUNTY.

Geographic relations.—Red River County adjoins Lamar County on the east and, like Lamar, lies between Red River on the north and Sulphur River on the south. It has an area of 1,061 square miles and a population of 28,564. The county seat is Clarksville. It is traversed from east to west by the Texas & Pacific Railway, which follows the crest of the divide between Red and Sulphur rivers.

The general slope to the southeast has the effect of throwing the principal part of the drainage into the Sulphur. The surface is rolling without marked relief and the drainage ways are for the most part inconspicuous. The most important tributaries are Pecan Bayou on the north and Cuthand Creek on the south. The plateau level ranges from about 530 feet above sea on the west to 390 feet above on the east. Detroit has an elevation of 482 feet; Bagwell, 476; Clarksville, 442; and Annona, 370.

Geology.—The geologic conditions in the northern and western parts of Red River County present essentially the same features as are found in Lamar County on the west. The outcrop of the Upper Cretaceous formations constitute a series of belts extending northeast two-thirds of the way across the county, where they disappear under a covering of Quaternary sands and gravels. In the northern part of the county the Woodbine sand appears along the south side of the Red River valley, bordered on the south by the clays of the Eagle Ford formation. Then comes the Blossom sand member of the Eagle Ford in a strip a mile or two wide extending from Blossom eastward nearly across the county to where the formation disappears beneath the alluvium of the Red River valley about 10 miles north of Annona. South of this comes the black-land area representing the outcrop of the chalk marls (Brownstown), chalk (Annona), and clay marls (Navarro and Taylor), each constituting a belt 5 to 6 miles in width, disappearing under the Quaternary deposits a short distance east of Annona. In the southern and eastern parts of the county the Cretaceous formations are entirely hidden from view by the early Quaternary (Port Hudson) deposits, which cover the higher areas,

[1] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 637.

and by the flood-plain deposits which occupy the valleys. Moreover, the Quaternary sands and gravels occur in broad, shallow depressions eroded in the Cretaceous area. A case in point is that of Cuthand Creek, the headwaters of which west of Clarksville are engaged in removing the filling of sand and gravel, occupying a depression in the surface of the chalk and chalk marls. The Annona chalk makes its appearance on the east side of this valley 6 or 8 miles southwest of Clarksville and extending northeastward constitutes the broad ridge on which the town is situated.

Water resources.—The areas in which shallow wells constitute a source of water supply are confined chiefly to the valleys of the main streams. Outside the valleys a few shallow wells, sunk in areas covered by the Quaternary sands and gravels, in places furnish an abundance of fairly good water, but not uncommonly are found to be too highly charged with deleterious substances to be used. Wells located in the northern part of the county on the outcrop of the Woodbine sand find water at depths varying from 20 to 40 feet. In general the water is good and the supply ample. The outcrop of the Blossom sand member constitutes a third but less important area of shallow wells. Water is found at a depth of 10 to 30 feet in this area, but it is likely to contain a large amount of mineral substances in solution. Wells differ greatly in the character of the water they furnish, those located near together often showing wide discrepancy.

Few surface wells have been dug in the Eagle Ford prairie or blackland areas; and such as have been attempted secure but a limited supply of water of poor quality in the seepage that finds its way along the joints of the clays and chalk.

The artesian conditions in Red River County are similar to those in Lamar County. The southward dip of the Trinity sand carries it too far below the surface to be available for wells located anywhere outside of the valley of Red River. It seems possible that flowing wells may be obtained in this formation in the lowlands bordering Red River, but in the absence of a suitable topographic map no definite prediction as to this can be made.

The Woodbine sand contains plenty of water, which when tapped by wells in the area to the south of the outcrop will tend to rise to the surface. The uncertainty of finding good water in the upper beds, however, makes these horizons of doubtful utility in this county. In an effort made some years ago to find artesian water the city of Clarksville drilled to the Woodbine sand, finding water at a depth of about 1,100 feet. The water, which was too salty for use, is reported to have been accompanied by natural gas and to have spouted out at the surface when first struck, but quickly subsided to 10 feet below the top. The elevation of the top of the well is about 430 feet, which indicates that flowing wells may be expected from this horizon in

locations having an altitude less than 420 feet. In 1902 the Clarksville Ice Co. put down a well to a depth of 1,800 feet, passing two water horizons, both in the Woodbine, one at 1,000 feet and one at 1,600 feet. The water from both these horizons was too strongly charged with salt for use. It appears that no attention was paid in either of these attempts to the horizon from which the present water supply of the city is obtained.

In 1902 the city of Clarksville [1] completed two wells, finding water in sand immediately underlying the chalk and chalk marl on which the city is located. This bed, to which the name Blossom sand member has been given, was reached at a depth of about 600 feet. The water, which rises to within 55 feet of the surface, is soft but rather high in alkalies, and the supply is apparently ample. The sands from which this supply comes outcrop along Pecan Bayou about 4 miles north of town. The elevation of the outcrop is about 400 feet, as determined by the aneroid, and the top of the well 450 feet, indicating that the Blossom sand member has a southward dip here of about 130 feet per mile. Assuming this rate of dip to continue it is evident the member will not be available as a source of water supply south of a line drawn east and west 7 or 8 miles south of Clarksville. Between this line and the outcrop of the member on the north the indications are favorable for good wells in this sand, but flowing wells can be expected only in those localities whose elevations are under 400 feet.

Indications of oil and gas are reported to have been found in a well 100 feet deep on the farm of Mr. Cox, about a mile north of Detroit. If correctly reported, these evidently came from sandstone lenses in the Eagle Ford clay.

BOWIE COUNTY.

Geographic relations.—Bowie constitutes the third and most easterly of the three counties occupying the narrow divide between Red River and Sulphur Fork. Its population is 4,827. Its width from north to south varies from 25 miles at the west end to 20 at the east. The relief is low and the crest of the divide, which is occupied by the Texas & Pacific Railway, is located north of the center line of the county. The divide slopes gradually eastward, as shown by the following list of elevations taken in order from west to east: DeKalb, 407; New Boston, 352; State line, 282.

Geology.—As shown on the map (Pl. I, p. 16), the larger portion of the area included between the flood plains of the two rivers is occupied by sands and gravels of Quaternary age. A considerable area in the southern and eastern part of the county is of Eocene (Wilcox) age, the north boundary of the formation extending through Old Boston

[1] For information concerning the Clarksville wells indebtedness is acknowledged to Mayor F. B. Mason.

and crossing the railroad track in the vicinity of Whaley station. New Boston is situated in a plain underlain by clay apparently representing the outcrop of the Midway formation (Eocene).

Three miles north of Malta station, on the Freeze place, is a small outcrop of the fossiliferous clay marl belonging to the undifferentiated Navarro and Taylor. The exposure occurs on the edge of a river terrace and has an area of about 2 square miles. Calcareous clay and greensand about 25 feet in thickness are here overlain by a thin capping of Quaternary sand and gravel. The locality is noted throughout the surrounding region for the Cretaceous shells found in the clays.

Water resources.—Throughout the county water is usually found in shallow wells varying in depth from 20 to 60 feet. The quality is in general good and the supply ample except in certain elevated localities where the water-bearing sands have been dissected by erosion. Instances are noted where wells when first drilled supplied good water, but after a time became highly charged with deleterious substances, especially hydrogen sulphide (HS_2). This is probably due to the entrance of low forms of plant life or to the decomposition of iron sulphide in the sand through the accession of air.

In the area covered by the Port Hudson (Pleistocene) deposits water is found in packsand or quicksand underlying clay near the middle or base of the formation, which does not usually exceed 60 feet in thickness. In the deeper wells the water is said to occur in a black sand immediately below a sandy clay "rock." Most wells are from 20 to 30 feet in depth. A few have been extended through the Port Hudson into the underlying clays of the Midway or the Cretaceous formations, but the results generally have not been satisfactory.

Where erosion has dissected the formation, exposing a bed of clay, springs are likely to occur at the top of the clay. Such a case is seen at De Kalb, where a fine spring occurs in a ravine about one-half mile southwest of the railroad station. The water, which is of good quality, flows out at the top of a dark-brown tough sandy clay.

In the Eocene area water is found in shallow wells at varying depths, from 20 to 50 feet, according to locality. The soils of this area are chiefly red and yellow sands, grading downward into partly consolidated sands and sandy shales, portions of which consist of hard ferruginous sandstone. The water from this horizon is usually more or less strongly mineralized. Dalby Springs, four in number, derive their supply from these beds; the water from them varies somewhat, but in all is rather strongly mineralized. (See p. 74 for analyses.)

In the eastern part of the county the Wilcox formation is more or less obscured by the later deposit of the Port Hudson. In this part of the county the water occurs in the surficial sands and gravels at depths varying from 15 to 45 feet. The supply of the Texarkana Water Co. is obtained from 52 wells located in a branch valley in the northeastern part of the city. The supply comes mainly from the surficial sands at from 15 to 45 feet below the surface.

Deep wells.—While several deep wells are known to have been put down in this county, only very meager information concerning them is at present obtainable. In 1905 a boring was completed a mile south of De Kalb to a depth of 1,833 feet in the search for oil and gas. The top of the well is about 350 feet above sea level, or 50 feet lower than the station. The only record obtainable of this hole is the following, given from memory by Mr. N. E. McKinney, the president of the company:

Record of well 1 mile south of De Kalb, Tex.

No.	Character.	Thickness.	Depth.
		Feet.	*Feet.*
1	Sand and sandy clay	93	93
2	Compact bed of clay with water below	7	100
3	Unrecorded	400	500
4	White rock	530	1,030
5	Blue clay. (Showing of oil and gas at 1,503)		

Water was encountered which at first overflowed and at the time of visit stood a little below the surface. No attention was paid to the water horizons nor to the character of the water. It is probable the water which rose to the surface came from the Blossom sand member, which was evidently penetrated at a depth of about 1,030 to 1,050 feet.

In 1898 a well was put down on the public square of New Boston to a depth of 1,270 feet, according to Mr. Paul G. Ruff. The drill is said to have passed through alternate strata of blue shale and sand rock, finding at about 500 feet one flow which rose to within 40 feet of the surface and another at about 700 feet; both flows were strongly salt. Mr. C. A. Berkshire states that the drill passed through about 450 feet of blue shale and then sand and sandy shale, with a number of beds of hard rock, to a depth of 1,200 feet. The water, which occurs in the sandy beds at a depth of about 500 feet, is highly mineralized and is not used except to some extent for watering stock. It is evidently from the Nacatoch sand. The elevation of the top of the well is 350 feet.

In 1906 a test well for oil and gas was drilled at Redwater to a depth of 2,000 feet. The well, which is located 450 yards west of the station, was completed April 30, 1906. It was drilled by

J. J. Boynton, who furnishes the record. The elevation of the collar is about 286 feet above sea level.

Well of the Redwater Oil & Mineral Co., Redwater, Tex.

Formation.		Character.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox ("Sabine").		1. Soil and clay	15	15
		2. Sand and water	2	17
		3. Lignite	4	21
		4. Sand	3	24
		5. Lignitiferous sand	4	28
		6. Light colored shale	4	32
		7. Black shale	8	40
		8. Gumbo	25	65
		9. Gray sands	2	67
		10. Yellow clay	13	80
		11. Lignitiferous sand	33	83
		12. Soft gray sand	2	85
		13. Yellow clay	20	105
		14. Soft brown shale	60	165
		15. Soft light shale	17	182
		16. Gray sand	36	218
Midway 269.		17. Black shale or gumbo	47	265
		18. Blue shale	67	332
		19. Hard sand	1	333
		20. Black shale	154	487
Navarro formation and Taylor marl.	Arkadelphia 565.	21. Shale and shells; some water in shell bed at 500	113	500
		22. Blue shale	40	540
		23. Black shale	240	780
		24. Hard dark-brown sand	1	781
		25. Soft black shale	79	860
		26. Shale with shells	40	900
		27. Black shale	80	980
		28. Hard lime	28	1,008
		29. Gumbo	4	1,012
		30. Lime	5	1,017
		31. Blue shale	35	1,052
	Nacatoch (?) 232.	32. Sandy shale	21	1,073
		33. Blue shale	67	1,140
		34. Lime (or sand?)	10	1,150
		35. Blue shale	20	1,170
		36. Brown sand	11	1,181
		37. Hard packsand	2	1,183
		38. Blue shale	97	1,280
		39. Sand and clay mixed	4	1,284
		40. Hard blue shale	10	1,294
	Marlbrook (?) 716.	41. Gumbo	24	1,318
		42. Black shale	12	1,330
		43. Gumbo	8	1,338
		44. Shale	40	1,378
		45. Sand rock	3	1,381
		46. Shale	34	1,415
		47. Gumbo	70	1,485
		48. Shale and shells	5	1,490
		49. Blue shale	16	1,506
		50. Black shale	494	2,000

No record was kept of any of the water sands except Nos. 2 and 21. No. 2 (15 to 17 feet) is the source of supply for the surface wells of the neighborhood. The beds believed to represent the Nacatoch horizon (1052 to 1294) are probably water bearing. This well did not reach the Austin group, under which lies the water-bearing Blossom sand member of the Eagle Ford, but it evidently stopped not far short of it.

A comparison of this record with that at New Boston indicates that the southward dip of the formations in this locality is about 60 feet per mile.

Several wells put down in Texarkana reach the water-bearing Nacatoch sand at a depth of 800 to 850 feet. According to the superintendent, Mr. R. A. Munson,[1] the well of the waterworks company has the following record:

Record of well of Texarkana Waterworks Co.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Quaternary or Lafayette	1	Dirt, sand, and gravel	50	50
Sabine (Wilcox)	2	White sand and clay, with water	45	95
Midway (?) and Arkadelphia.	3	Dark blue clay, no water	730	825
Nacatoch	4	Sand and sand rock, water bearing	100	925
Marlbrook[a]	5	Blue clay	5	930

[a] Veatch assigns No. 5 to the Marlbrook, but the more complete record of the Oil Prospect well shows it to be evidently Nacatoch.

Analysis[1] shows the water to be highly mineralized. It is used only occasionally to supplement the supply from the shallow wells.

A well put down by the American Well & Prospecting Co. for the Home Ice Co.[2] was drilled to a depth of 1,900 feet, with the following results:

Record of well of Home Ice Co., Texarkana, Tex.

Formation.	No.	Character.	Thickness.	Depth.
			Feet.	*Feet.*
Lafayette (?)	1	Coarse gravel	6	6
Lower Eocene (?)	2	Yellow clay	29	35
Lower Eocene and Arkadelphia.	3	Blue clay	845	880
	4	Sand containing brackish water which rose within 15 feet of the surface.	20	900
Nacatoch	5	Hard sandstone	11	911
	6	Sand containing brackish water which rose within 5 feet of surface.	30	941
Marlbrook	7	Blue clay	759	1,700
Annona	8	White chalky limestone	125	1,825
Brownstown	9	Blue clay	75	1,900

A similar record is shown by a well (No. 480) which was drilled in 1907 by J. J. Boynton, as an oil prospect, 1 mile northeast of the city, and was abandoned at 1,390 feet.

The Texarkana oil prospect well is located in the creek bottom at an elevation about 305 feet. The record was furnished by Mr. J. D. Cook. The well is cased with 11⅝-inch pipe to 145 feet, with 9-inch pipe to 860 feet, and with 6-inch pipe to 1,360 feet.

[1] Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 180, 261.

[2] Idem, pp. 180, 265.

Record of well of Texarkana Oil Prospect Co.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
	1	Soil and clay	5	5	
	2	"Packsand"	40	45	
Recent.	3	Quicksand	10	55	
Wilcox, 145 feet.	4	"Packsand"	55	60	
	5	Hard bowlders	2	62	
	6	"Packsand"	43	105	
	7	Quicksand	5	110	
	8	"Packsand"	35	145	
	9	"Hard rock"	3	148	
	10	Blue shale	27	175	
	11	"Hard rock"	44	179	
	12	Black shale	10	189	
	13	Gravel	20	209	
	14	"Hard rock"	1	210	
	15	Blue shale	8	218	
	16	"Packsand"	2	220	
	17	"Gumbo shale"	26	246	
	18	Gravel	4	250	
	19	Shell rock	4	254	
	20	Blue shale	3	257	
	21	Gumbo	24	281	
	22	Rock	4	285	
	23	Gumbo	18	303	
Midway, 289 feet.	24	Rock	5	308	
	25	Blue shale	10	318	
	26	Gravel	3	321	
	27	Shale	15	336	
	28	Sand	4	340	
	29	Gravel	8	348	
	30	Gumbo shale	20	368	
	31	"Rock"	6	374	
	32	Shale	2	376	
	33	Soft black shale	5	381	
	34	Hard shale	3	384	
	35	"Rock"	4	388	
	36	Shale	7	395	
	37	Gravel	2	397	
	38	"Gumbo shale"	35	432	
	39	Gravel	2	434	
	40	Gumbo	38	472	
	41	Blue shale	30	502	
	42	"Bowlders"	3	505	
	43	Blue shale	37	542	
	44	"Bowlders"	2	544	
	45	Gumbo	16	560	
Arkadelphia, 408 feet.	46	"Bowlders"	4	564	
	47	Shale	108	672	
	48	Lime	18	690	
	49	Blue shale	10	700	
	50	Gumbo	14	714	
	51	Blue shale	20	734	
	52	Gumbo	102	836	
	53	"Rock and bowlders"	6	842	
	54	Gray sand	2	844	
	55	Gravel	2	846	
	56	Blue shale	4	850	
	57	"Hard sand" (sandstone)	20	870	9-inch casing to 860 feet.
	58	"Packsand"	8	878	
	59	Gray sand, water	35	913	
	60	"Hard rock"	4	917	
	61	"Hard sand," water	10	927	
	62	Shale	30	957	
	63	Loose sand, water	13	970	
	64	"Rock"	6	976	
	65	Shale	44	1,020	
Nacatoch, 347 feet.	66	Black sand, water	20	1,040	Strong flow, came almost to top.
	67	Shale	10	1,050	
	68	"Rock"	1	1,051	
	69	Shale	16	1,067	
	70	"Rock"	6	1,073	
	71	Hard sand, water	25	1,098	
	72	"Rock"	3	1,101	
	73	Gray sand, water	38	1,139	
	74	"Rock"	3	1,142	Water comes within 25 feet of the top.
	75	Blue shale	10	1,152	
	76	"Hard rock"	4	1,156	
	77	Soft sand, water	14	1,170	
	78	"Crevice rock"	4	1,174	
	79	Black sand, water	15	1,189	Strong pressure water.

Record of well of Texarkana Oil Prospect Co.—Continued.

Formation.	No.	Character.	Thickness.	Depth.	Remarks.
			Feet.	*Feet.*	
	80	Shale	2	1,191	
	81	Gumbo	30	1,221	
	82	Blue shale	8	1,229	
	83	Gumbo	21	1,250	
	84	Black shale	16	1,266	
	85	Gumbo	6	1,272	
	86	Shale	8	1,280	
	87	"Crevice rock"	12	1,292	
Marlbrook, 441 feet.	88	Gumbo	20	1,312	
	89	Shale	10	1,322	
	90	Gumbo	16	1,338	
	91	Shale	12	1,350	
	92	White chalk rock	50	1,400	6-inch casing to 1,360 feet.
	93	Blue and black shale	97	1,497	
	94	Hard shell rock	13	1,510	
	95	Blue shale	75	1,585	
	96	Hard shell rock	15	1,600	
	97	Black shale	30	1,630	
	98	White chalky lime	35	1,665	
	99	Black shale	10	1,675	
	100	White chalky lime	80	1,755	
	101	Lime with shells	15	1,770	
	102	Black shale	70	1,840	
	103	Gumbo	30	1,870	
	104	Black shale	35	1,905	
	105	Gumbo	63	1,968	
Austin, 459 feet.	106	Sand with shells	12	1,980	
	107	Black shale	16	1,996	
	108	Gumbo shale	18	2,014	
	109	Soft black shale	27	2,041	
	110	Gumbo	6	2,047	
	111	Black shale	15	2,062	
	112	Gumbo	18	2,080	
	113	"Rock" (concretion?)	2	2,082	
	114	Gumbo	7	2,089	
	115	Hard sand	7	2,096	
Blossom sand member of Eagle Ford clay, 42 feet.	116	Gray sand, water	17	2,113	Water salty. Rose rapidly to 1,500 feet, then slowly to top.
	117	Hard sand rock	18	2,131	
	118	Dark blue or black shale	79	2,210	
	119	"Emery rock" (hard rock cut drill badly.)	5	2,215	
	120	Hard sand	15	2,230	
	121	Sand, softer	4	2,234	Water lost here.
Lower clays of Eagle Ford clay and Woodbine sand, 174 feet.	122	Hard sand	11	2,245	
	123	Black shale	10	2,255	
	124	Hard sand	23	2,278	
	125	Light blue shale	14	2,292	
	126	Hard rock	10	2,302	
	127	Rock softer	3	2,305	

A comparison of the foregoing record with records published by Veatch[1] shows some discrepancies in the thicknesses of the different formations. These discrepancies may be attributed doubtless to the incompleteness of the earlier records, together with the varying character of some of the formations. In the ice company's well one chalk bed only is noted, and this is found at a depth of 1,700 feet. In the oil prospect well three chalk beds are penetrated, one at 1,350, one at 1,630, and one 1,665 feet. It is evident that the 125 feet of chalky limestone in the ice company's well represents the two lower beds with their associated marls or shales (Nos. 98, 99, and 100), and that the upper bed of chalk No. 92 evidently grades horizontally into blue

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 261-265.

marly clays which are included in the blue clays assigned to the Marlbrook in the ice company's well. Likewise, the greater thickness of the Nacatoch (347 feet) is probably to be accounted for by local variation in the character of the beds assigned to the lower part of the Arkadelphia or the upper part of the Marlbrook, or perhaps to lack of care in keeping the record.

From the data furnished by the above records it is shown that although the Nacatoch sand furnishes an abundance of water, its quality is such as to make it unfit for domestic use. The water found in the Blossom sand (Nos. 115–117) is too highly charged with saline constituents for use. The bed was not reached in the Redwater well. The only locality in which the Blossom sand member seems likely to constitute a possible source of water supply is in the western part of the county. From DeKalb westward this sand should be reached at from 1,000 to 1,300 feet, according to locality, and in some places the water will doubtless flow out at the surface. The quality of this water differs greatly from point to point, and no reliable statement can be made as to what its quality may be at any place. At Clarksville it is of good quality and this is likely to be true of it in some other places.

HOPKINS AND FRANKLIN COUNTIES.

Topographic relations.—Hopkins and Franklin counties lie just within the northern boundary of the Eocene and have the general relief of an eastward (coastward) sloping plain dissected by the branching tributaries of South Fork of Sulphur River on the north (mainly through White Oak Creek), and of Sabine River through Lake Fork on the south. The drainage of the region is divided about equally between the two systems. On the south and east the surface is diversified by many low eminences mostly rounded out of the unconsolidated sands, but in the extreme southern part of the area the interstream areas present a flat-topped, mesalike appearance, due to the capping of a more resistant layer of hard iron conglomerate. In the north and west a narrow strip of high-rolling prairie constitutes the eastward continuation of the prairie region of the adjoining county and has the White Oak bottom as its eastern limit. Cumby and Ridgeway, the two highest points in the district, are located on this prairie. The drainage ways are for most part broad and shallow and are occupied by insignificant streams, which in the summer or dry season consist merely of a chain of pools. White Oak bottom has an average width of about 3 miles. All the smaller streams are completely dry during the summer season. The population of Franklin County is 9,331, and that of Hopkins County is 31,038.

Geology.—Hopkins and Franklin counties lie on the northern edge of the eastern timber belt, which represents the outcrop of the Eocene

Tertiary. The formations consist for the most part of unconsolidated sands and clays, with local beds of lignite and ferruginous sandstones and iron ore. Owing to the nonpersistent character of the stratification and the lack of fossils, no general sequence can be worked out in the stratigraphy of the region. It is clear, however that South Fork of Sulphur River marks the northern boundary of the Eocene in this region and that the beds belong to the Wilcox formation.

In prospecting for water at Sulphur Springs the city corporation put down, to a depth of 1,515 feet, a well, the record of which has been kindly furnished by Mr. W. B. Baxter. This section is instructive as showing the thickness and character of the formations constituting the lower Eocene in this region. The collar of the well is 500 feet above tide.

Record of city well, Sulphur Springs, Tex.

Formation.	No.	Character rock.	Thickness.	Depth.
			Feet.	*Feet.*
Wilcox.	1	Surface soil	1	1
	2	Red clay	8	9
	3	Lignite	2	11
	4	White sand with water; source of supply for most of the wells of the region.	4	15
	5	Blue sandy shale	18	33
	6	Buff sandstone	2	35
	7	"Pipe clay"	2	37
	8	Black shale with mica	15	52
	9	Sand with water; furnishes city supply	16	68
	10	Shale	59	117
	11	Limestone	1	118
	12	Black shale interlaminated with lighter colored shale; contains iron concretions, iron pyrites, and mica.	565	683
	13	Hard limestone	1	684
	14	Black shale in thin layers with fossils	20	704
	15	Light-colored shale	8	712
	16	Blue shale	88	800
	17	Black shale with iron concretions; and fossils; *Venericardia planicosta.*	10	810
Midway, 324½.	18	Blue shale	90	900
	19	White clay	20	920
	20	Blue shale	80	1,000
	21	Hard sandstone	4	1,004
	22	Blue shale	30	1,034
	23	Fine sand; some water	2	1,036
	24	Soft white clay	15	1,051
	25	Gray sandstone	40	1,091
	26	White "pipe" clay	2	1,093
	27	Sandstone	15	1,108
	28	Hard blue shale	2	1,110
	29	Soft sandstone	15	1,125
	30	Hard sandstone	2½	1,127½
	31	Hard blue shale	5	1,132½
	32	Fine gray sand	1	1,133½
	33	Very hard sandstone	1	1,134½
Navarro and Taylor, 381.	34	Hard blue shale	171	1,305½
	35	Sand with some water	14	1,319½
	36	Blue shale and sand	95	1,414½
	37	Blue shale; some sand with mica	101	1,515½

The upper 1,134 feet of this section are assigned to the Wilcox and Midway, the division between these being placed tentatively at the base of No. 17. The beds below No. 33 apparently represent the Navarro formation and Taylor marl.

Ridgeway and Cumby are located on a prairie composed of dark soil underlain by yellow calcareous clay in some instances showing the presence of greensand. Some fossils obtained from this clay a few miles north of Cumby are reported by Dr. T. W. Stanton to be "probably of Tertiary age, but they contain no distinctive forms that fix the exact horizon." The stratigraphic relations indicate that the narrow strip of prairie extending from Cumby past Ridgeway represents the outcrop of the Midway clay and shale beds (Nos. 18–22). North of Sulphur Bluff, in the northeastern part of the county, a narrow prairie of black soil overlies yellow calcareous clay over blue chalky sand. Three miles north of this, on the south side of South Fork, 42 feet of blue and black sandy shales and shaly sands, which is strongly bituminous and contains many Cretaceous fossils (pp. 27, 28), outcrops in a bluff, where it apparently represents the lowermost beds of the Sulphur Springs well. This strip of black land is said to extend down the river as far as Goolesboro, in Titus County, where it disappears beneath the alluvium of the valley.

In the vicinity and south and east of Mount Vernon the higher elevations are capped by a deposit of unconsolidated yellow and red sand, white clays, and gravels which rest upon the apparently eroded surface of the Wilcox formation. Both sands and clays are usually distinctly cross-bedded and the contact with the underlying formation is frequently marked by a layer of ferruginous sandstone or iron ore, sometimes in broken blocks irregularly distributed along the plane of contact. These overlying beds are probably of late Tertiary age, though no evidence that would fix their age is at hand.

Deposits of lignite are reported from different localities, but the beds are usually thin and of small horizontal extent. A bed 2 feet thick is reported in the Sulphur Springs well at a depth of 9 feet and similar occurrences are reported in the vicinity of Mount Vernon in Franklin County. At Como, 10 miles south of Sulphur Springs, a bed of lignite 7 feet thick, found at a depth of 75 feet, has been successfully worked for the past six years. The lower 2 feet of the deposit is unavailable on account of impurities. The roof is composed of compact sand and the mine is entirely free from water. This bed comes to the surface 1½ miles north and borings do not indicate workable thickness outside a very small area. Fifteen feet above the Como vein is another bed 2½ feet thick, and 45 feet above is one 2 feet thick. The following record of a shaft put down a number of years ago somewhere in this vicinity is published in the Texas reports.[1]

[1] Dumble, E. T., Report on brown coal and lignite of Texas, 1892, p. 161.

Record of shaft near Como, Tex.

	Feet.
1. Clay	6
2. Sandrock	10
3. Slaty clay	4
4. Brown coal	16
5. Sands and clays	9
6. Plastic clay	30
	75

In places the sands are indurated to form ferruginous sandstones, which weather out in irregular masses and have some use for building and paving, and by the railroads for ballast. No workable deposits of iron ore are reported in this district.

Water conditions.—In the prairie areas cisterns are the sole reliance for water for domestic use. In the remaining areas shallow wells are abundant, the surface sand overlying a clay being a good reservoir. The water is, however, at times mineralized and many persons residing on the sandy lands have cisterns; some have both wells and cisterns. Sulphur Springs is now supplied by a rain reservoir, but for a long time, until it outgrew them, it was amply supplied by three wells.

In the sandy wooded region, the larger portion of which drains southward through Lake Fork and Big Cypress Creek, an abundant supply of water is found in the surface sands at depths varying from 20 to 40 feet. Along the slopes springs are of frequent occurrence. In localities underlain by formations in which clay predominates some difficulty is found in obtaining sufficient supplies of water. The character of the water is quite variable, in some localities being soft and agreeable and in others more or less strongly mineralized. At Mount Vernon, Franklin County, the supply for domestic use is drawn chiefly from shallow wells and cisterns.

Deep wells.—Very few attempts have been made to exploit the deep-lying water beds and the information concerning their extent, character, or location is very meager. The most serious attempt made was that at Sulphur Springs by the city authorities, who drilled to a depth of 1,515 feet without satisfactory results. The record of this well (p. 61) shows that below the upper "veins," Nos. 4 and 9, the only water encountered was a small flow at a depth of 1,034 feet and another at 1,303 feet. At Mount Vernon, Franklin County, the railroad has a 400-foot well which yields a large supply by pumping.[1] No information is available as to the horizon from which the water is derived. At Cumby, wells 300 feet deep fail to find water below the surface supply.

As to the Cretaceous horizons, very few data are available. The record of the Sulphur Springs well indicates, however, that owing

[1] Veatch, A. C., Prof. Paper U. S. Geol. Survey No. 46, 1906, pp. 230–231.

to the thickness of the post-Cretaceous deposits over most of this region the possibility of exploiting the underlying water horizons is exceedingly remote. The only district in which there is any possibility of obtaining water from the Cretaceous beds is in the extreme northern part of Hopkins County, and the lack of knowledge of the extent and water-bearing character of these beds makes hazardous any prediction concerning them. The conclusion seems warranted, however, that in the valley of the Sulphur Fork, and for 4 or 5 miles to the south, the Nacatoch sand may be reached at depths varying from 500 to 1,000 feet. At Commerce, in Hunt County, which is 9 miles northwest of Ridgeway, these sands were reached at 370 feet. They outcrop between Commerce and Fairlie, 6 miles northwest of Commerce, giving an estimated dip of 50 feet per mile. From this it would appear that these beds may be reached at Ridgeway at a depth of 800 to 1,000 feet and the lower sands about 200 feet deeper. No prediction can be made as to the water-bearing character of the latter beds; the upper or Nacatoch sand is water-bearing at Commerce, but the water is not used because of its mineralized character.

CASS COUNTY.

Topography.—Cass County is in the northeastern part of the State, adjoining the Louisiana State line; it is bounded on the north by Sulphur Fork, and on the south and west by the counties of Marion and Morris, respectively. Its area is 945 square miles and its population 27,587. Linden is the county seat. The county is traversed by two railroads—the Missouri, Kansas & Texas and the Texas & Pacific.

The region constitutes the eastern extension of the general coastward-sloping plain of the eastern timber belt and differs from the counties to the west only in the greater degree to which the original plain level has been dissected by erosion. The drainage is principally to the southeast through small streams emptying into Caddo Lake, Sulphur Fork on the north receiving but a small part of the run-off through a few short tributaries. The surface is decidedly rolling and is characterized in the main by long ridges extending from northeast to southwest, or in a direction at right angles to this. These ridges are separated by steep-sided, narrow, deep ravines, the bottoms of which are generally occupied by narrow streams fed by the numerous springs found everywhere along the sides of the ridges.[1] In some of the ridges deposits of laminated iron ore occur in thin seams at depths of 20 to 40 feet below the summits. Such ridges usually present a terraced appearance due in part to the differential erosion of the hard and soft layers and in part, doubtless,

[1] Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 67–68.

to landslides brought about by the undermining action of springs which find their way out of the greensands that underlie the ore beds.[1]

The following elevations are shown by the railroad profiles: Alamo, 242; Atlanta, 264; Avinger, 393; Bivens, 314; Hughes Springs, 373; Kildare, 311; Queen City, 349.

The tops of the hills are from 50 to 100 feet above the level of the flood plains of the principal streams and have a general elevation of between 500 and 600 feet above tide level. On the north the wide flood plain of Sulphur Fork is bounded by a relatively narrow northward-facing drainage slope intersected by few and short tributaries.

Geology.—The county lies entirely upon the outcrop of the Wilcox formation and, like the district on the west, is characterized by timber-covered slopes and sandy soils. The deposits exposed within the limits of the county present the twofold division noted in the counties farther west, viz, an upper unstratified deposit of sand with local deposits of iron ore and a lower division of stratified sands, sandy clays, and clays with local deposits of lignites.

The upper part of the lower division consists of thinly laminated red, yellow, and white sands and sandy clays, blending horizontally and vertically in places into unstratified mottled red and white sands. The clays are usually dark blue, gray, or black, or in places red, yellow, or white; they occur interstratified and interlaminated with the sands and are generally sandy, though in places fairly free from sand. These beds are well exposed in the vicinity of Queen City, where they have a thickness of 65 feet or more, for which reason they have been given the name Queen City in the Texas reports.

Below these beds is a series of black, blue, and gray micaceous sands, blue, brown, and gray clays, and beds of lignites of varying thickness and generally of local extent. In places the sands are said to contain thin strata of sandstones and limestones.

Deposits of brown coal appear in different parts of the county, the best occurrences being reported from the northeastern portion, at Alamo and Stone Coal Bluff. At the former locality a bed of brown coal, 4 feet 7 inches thick, was found at a depth of 52 feet and another bed, 1 foot 8 inches thick, 11 feet higher. At Stone Coal Bluff a bed of coal 12 feet thick is said to occur at the bottom of the river.[2]

Resting on the irregular worn surface of the stratified lignitiferous sands and clays constituting the lower division are yellow, brown, and red pebbly sands, for the most part unstratified, ranging from a few feet to 100 feet in thickness. These sands contain the iron-ore deposits of the region, which appear as a kind of pavement

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 84-86. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 68-70.

[2] Shumard, B. F., First Rept. Progress Geol. Survey Texas, p. 12.

under the sands capping the ridges or as aggregations of bowlders accumulated along the slopes.

According to Kennedy, with the exception of some small deposits of laminated ore, no continuously bedded ores occur within the county. For the most part the ores consist of rounded, oval, or lenticular concretionary masses, which in places have the appearance of a regular bed, but which change horizontally into ferruginous sandstone or into the irregular or rudely rectangular blocks of conglomeratic ore usually found along the valley sides or capping the lower hills. The ore deposits vary in thickness from a few inches to a maximum of 10 feet,[1] and for the most part are limited to the surface. Parties who have worked and prospected the ores for years state that on following them into the hills the ore is replaced by dark ferruginous sand. The best deposits are reported to occur southwest of Hughes and east of Linden.

FIGURE 6.—Diagrammatic section of strata near Atlanta, Cass County.

In a railroad cut one-half mile north of Atlanta the beds have the relations shown in figure 6.

Here 4 to 12 feet of red and yellow sand containing irregular masses of low-grade iron ore, blocks of which occur distributed along the plane of contact, rest unconformably upon laminated sand or sandy clay, with little appearance of grit.

The relations of the formations on the western side of the county are shown in the accompanying section, compiled from a series of exposures in railroad cuts north of Hughes:

Composite section in railroad cuts north of Hughes, Tex

	Ft.	in.
1. Soil and reddish-brown sand with pebbles	4 to	2
2. Yellow and red sand, containing concretionary masses of low-grade iron ore. Portions of the beds are indurated to a hard ferruginous sandstone	8	
3. Laminated red and white sand, sandy clay, locally white mottled clays, containing nodular, concretionary iron ore	4	
4. Brown lignitic sands and sandy clays, and laminated black clay	8	
5. Brownish-red sand interlaminated with fine white sandy clay	25	
6. Lignite		3
7. White sand mottled with red; exposed	3	
	68	3

The age of this upper deposit of sand with its concretionary and conglomerate ores has not been clearly determined. In the Tex

[1] Penrose, R. A. F., First Ann. Rept. Geol. Survey Texas, 1889, pp. 35–65. Kennedy, William, Second Ann. Rept. Geol. Survey Texas, 1890, pp. 65–95.

reports the areas in which the iron ores occurred were regarded as outliers of the lower (Mount Selman) division of the lower Claiborne (St. Maurice). That the ores had their source in the Claiborne beds may be admitted, but their present condition may be due to rearrangement by erosion during late Tertiary time.

Water resources.—The supply of water for domestic and stock purposes in Cass County is obtained almost entirely from shallow wells 20 to 50 feet deep, the most common depth being 30 to 40 feet. The supplies are derived mostly from surficial sands, but in some places come from the lower sand horizons. The water from the surficial sands is usually soft and of good quality, but locally becomes mineralized to a greater or less extent.

Springs are of frequent occurrence wherever the base of the surficial sands has been reached by erosion, but in general are small and are but little used. They are frequently chalybeate in character, that at Hughes having for a long time sustained an excellent reputation for its medicinal properties. Another spring, owned by Mr. Charles Thrasher, 5 miles east of Linden, is also worthy of note. Analyses made in the laboratories of the Survey (p. 74) of the waters of these two springs show them to be very much alike.

The supply of water derived from the surficial sands is in the main ample for present requirements for domestic and stock purposes, but it is not sufficient to meet manufacturing or city needs, to supply which resort is had to rain tanks.

So far as can be learned no attempts have been made to exploit any of the deeper water horizons in Cass County. At Jefferson, in Marion County, 10 miles south of the boundary of Cass, a well put down many years ago to a depth of 802 feet in the search for coal struck a strong flow of water with sufficient pressure, according to reports, to rise 35 or 40 feet above the surface when piped. At first the flow is said to have been very strong, but caving at the bottom resulting from drawing the pipe back 80 feet has greatly diminished the pressure. At present the flow is about a gallon a minute. Kennedy reports as follows concerning this well: "The drill passed through alternate strata of sands, clays, and lignites to a depth of 802 feet. Three heavy beds of lignite and a number of smaller ones are said to have been passed through in the boring."[1]

According to Mr. J. M. De Ware, corroborated by Mr. W. T. Atkins, this well is about 830 feet deep. The elevation at the top is about 196 feet. The water is rather strongly mineralized and has a high reputation locally. (See analysis, p. 74.)

Veatch states[2] that this water comes from the Nacatoch sand. In the absence of satisfactory data no definite statement can be made.

[1] Proc. Acad. Nat. Sci. Philadelphia, for 1895, 1896, pp. 126–127.
[2] Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 222.

but it seems probable that the source is the lower portion of the Wilcox formation.

If this water horizon is persistent it will undoubtedly be found underlying the whole of Cass County at depths varying from 800 to 1,200 feet, according to locality. In some places the water would no doubt be too strongly mineralized to be of general use, but from the variable character of the water from the Wilcox formation it is not improbable that good wells might be developed in localities 10 to 20 miles away.

Nothing is known of the Cretaceous horizons in this region, but the inference is that they are not practically available, owing to their excessive depth and to the highly mineralized character of the water they yield.

The following table gives the obtainable data in regard to the wells of the region:

Data concerning wells in northeastern Texas.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
	Bowie County:				*Inches.*	*Feet.*	*Feet.*
1	De Kalb, 13 miles north	S. L. Moore	Hudson and Cornelius	Hudson and Cornelius	2	425	
2	De Kalb, 1 mile south	N. E. McKinney		N. E. McKinney		1,833	350
3	New Boston	Town of New Boston	John Lowdermilk	John Lowdermilk	$3\frac{3}{4}$	536	352
4	Do			C. K. Berkshire	5	1,200	352
5	Pope post office	Cass Pope		Cass Pope	6	196.5	
6	Rolyat, 4 miles north			Postmaster		247	
7	Rolyat, 3 miles west	I. N. Phillips		I. N. Phillips	6	165	
8	Rolyat	Postmaster		Postmaster	8	119	
9	Redwater	Redwater Oil & Mineral Co	J. J. Boynton	J. J. Boynton		2,000	286
10	Texarkana (Tex.)	Taxarkana Ice Co		R. A. Munson		63	
11	Do	Jack Weed	John Lowdermilk	John Lowdermilk		550	
12	Texarkana (Ark.) [1]	J. D. Cook et al	J. J. Boynton	J. J. Boynton, J.D. Cook	$11\frac{5}{8}$–6	2,305	305
	Cass County:						
13	Hughes Spring [2]	Hughes Spring					
14	Linden, 5 miles east	Chas. Thrasher		W. H. Crow			
	Camp County:						
15	Pittsburg	W. C. Hargrove et al		W. C. Hargrove	6–4	1,860	395
16	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 1.).		E. L. Wells, jr., manager	6	263	395
17	Do	Arkansas & Texas Consolidated Ice & Coal Co. (No. 2)		do	6	$273\frac{3}{4}$	395
	Delta County:						
18	Cooper, 3 miles west	E. H. Bond		E. H. Bond		263	495
19	Horton					315	
20	Klondike					160	478
	Fannin County:						
21	Honey Grove	Honey Grove		Postmaster		1,700	
22	Ladonia [3]					1,035	625
	Franklin County:						
23	Mount Vernon	St. Louis Southwestern Ry		A. J. Patton, county clerk		400	476
	Hopkins County:						
24	Cumby	Cumby				300	649
25	Sulphur Springs	Sulphur Springs		W. B. Baxter	6–4	1,514	503

[1] For records of other wells at Texarkana see Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 180.
[2] Analyzed by A. C. Peale, Bull. U. S. Geol. Survey No. 32, 1886, p. 135.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Owner.	Driller.	Authority.	Diameter of well.	Depth of well.	Elevation of surface. (Approximate.)
	Hunt County:				*Inches.*	*Feet.*	*Feet.*
26	Commerce [a]			H. G. Johnston		2,390	548
27	Do	Capt. Anders				370	548
28	Do	Texas Midland R. R				900	548
	Lamar County:						
29	Blossom	W. E. Moore		W. E. Moore		146	530
30	Do	Blossom				117	530
31	Paris, 2½ miles east	Paris Waterworks Co	H. G. Johnson	J. A. Porter, W. F. Gill		1,965	510
32	Paris	Texas Midland Ry		E. H. R. Green, president		73	566
	Marion County:						
33	Jefferson, 400 yards north of post office	J. M. De Ware		J. M. De Ware		830	196
	Morris County:						
34	Daingerfield	Joseph Bradfield		Joseph Bradfield		186	400
35	Omaha, 4 miles from	M. C. McCollum		M. C. McCollum		100	
	Red River County:						
36	Clarksville (public square)	Corporation Clarksville		Frank B. Mason, Mayor		1,100	410
37	Clarksville, ¼ mile west of station	do			8–6	600	450
38	Clarksville	Ice factory		Frank B. Mason, Mayor		1,800	
39	Lydia, 4 miles south	W. S. Perkins		Postmaster		200	260
40	Towson, 3 miles above, on bank of Red River.	S. J. Wright		S. J. Wright	6	300	
	Titus County:						
41	Mount Pleasant	H. W. Cheney et al		H. W. Cheney	7–6¼	300	

[1] Hill, R. T., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 7, 1901, p. 636.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (−) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
	Bowie County:	*Feet.*	*Feet.*	*Gallons.*	*Gallons.*			
1	De Kalb, 13 miles north		−2		Very small.			Abandoned.
2	De Kalb, 1 mile south	− 0	(?)	Small.		(?)	Salty	Trace of oil and gas at 1,503.
3	New Boston		500–536			Navarro	do	
4	Do	−60	±500			do	do	Casing 200. Used somewhat for watering stock.
5	Pope post office	+60	145–196			do	Soft	
6	Rolyat, 4 miles north				None.			
7	Rolyat, 3 miles west	−60				Navarro	Hard, alkaline	Drilled in 1900.
8	Rolyat	−49				do	Soft	Drilled in 1902.
9	Redwater		500 1,170?			Navarro-Taylor.		Drilled in 1906.
10	Texarkana (Tex.)	−20	33–63		Large.	Wilcox	Soft	
11	Do	− 0	136 550			Navarro		Lower horizon doubtful.
12	Texarkana (Ark.)	−25 − 0	878–1,190 2,096			Navarro Woodbine.	Soft	Water found down to 888 salty and sulphureted. Cased off. Well completed in 1907.
	Cass County:							
13	Hughes Spring	Spring.		Moderate.		Wilcox	Chalybeate	Local resort.
14	Linden, 5 miles east	Spring.		Moderate.		do	do	
	Camp County:							
15	Pittsburg	*a* −8	220 750 1,700			Wilcox do Navarro	Soft	Cased to 400; drilled in 1900.
16	Do	−20	150–200		50	Wilcox	do	
17	Do	−20	160–200		50	do	do	
	Delta County:							
18	Cooper, 3 miles west							No water, except seep from clays.
19	Horton		315					
20	Klondike							No water; abandoned.
	Fannin County:							
21	Honey Grove				Plenty.		Mineral	Can not be used even for stock without mixing with pure water.
22	Ladonia							Abandoned.
	Franklin County:							
23	Mount Vernon	No flow.			Large.	Wilcox		

a Lowers to 70 feet when pumped.

Data concerning wells in northeastern Texas—Continued.

No.	Locality.	Height of water above (+) or below (−) ground.	Depths of principal water-bearing strata.	Yield per minute.		Geologic horizon of water-bearing strata.	Quality.	Remarks.
				Flow.	Pump.			
	Hopkins County:	*Feet.*	*Feet.*	*Gallons.*	*Gallons.*			
24	Cumby							No water below 40 feet.
25	Sulphur Springs				Small.	Wilcox		Drilled 1900. "Found no sand worth developing."
	Hunt County:							
26	Commerce							"Well was a failure."
27	Do	−90	370			Navarro	Soft	
28	Do		385 900			do	do	"Not good for boilers."
	Lamar County:							
29	Blossom	−25	25–35			Blossom	Hard	Used occasionally.
30	Do	−25	25–35		Small.	do	Hard, mineralized	
31	Paris, 2½ miles east	− 2	0–80 570–1 412 1,635			do Woodbine Washita	Mineralized	Drilled in 1896.
32	Paris		18–33		8	Blossom		
	Marion County:							
33	Jefferson, 400 yards north of post office	+35±	300 500 800			Wilcox	Mineral	"Now clogged by caving."
	Morris County:							
34	Daingerfield	−20	186		"Inexhaustible."	do	Some mineral	
35	Omaha, 4 miles from				Large.		Mineral	Not used.
	Red River County:							
36	Clarksville (public square)	−10	556 ±1,050		Large.	Blossom Woodbine	Brine	Water accompanied with natural gas.
37	Clarksville, ¼ mile west station	−55	550–600		Large.	Blossom	Good, soft	2 wells drilled in 1902.
38	Clarksville		1,009 1,600?		Large.	Woodbine	Brine	Drilled in 1902.
39	Lydia, 4 miles south				Not any.			
40	Towson, 3 miles above, on bank of Red River	[a] Flow.	300	Large.		Trinity	Soft	Drilled in 1892.
	Titus County:							
41	Mount Pleasant							Test for oil, incomplete.

[a] Would flow if piped. Drill lost by caving and well abandoned.

CHEMICAL COMPOSITION OF THE WATERS.

The available information regarding the chemical composition of the waters of northeastern Texas is given in the following table. The number of analyses is too small to permit much generalization regarding the mineralization of the waters. Those tested from the Sabine formation seem to be much superior in quality to those from other underground sources. The waters from the Blossom sand member at Blossom are very high in calcium, magnesium, alkalies, and sulphates, being similar in these respects to the waters tested from the Eagle Ford clay. The single well tested drawing its supply from the Nacatoch sand yields a brine. The analyses are stated in parts per million in ionic form. Most of them were made especially for this report, and the few obtained from other sources have been recomputed to ionic form in order to facilitate comparison.

Chemical composition of underground waters of northeastern Texas.

[Parts per million unless otherwise stated.]

	County.	Town.	Source.	Owner, name, location, etc.	Water-bearing formation.	Date of collection.	Analyst.
1	Bowie	Dalby Springs	Springs		Wilcox		
2	do	New Boston	Well	City supply	Nacatoch	Sept. 10, 1907	R. B. Dole and M. G. Roberts.
3	do	do	do	do	do	do	Do.
4	Cass	Hughes Springs	Springs	H. R. Hughes	Wilcox	Sept. 12, 1907	B. L. Glascock.
5	do	Linden	Well	W. H. Coon	do	Nov. 15, 1907	J. R. Bailey and A. M. McAfee.
6	Delta	Ben Franklin	Creek			Jan. 9, 1902	W. A. Powers.
7	do	do	do			Sept. 30, 1902	Kennicott Water Softener Co.
8	Harrison	Marshall	Well		Wilcox	Sept. 19, 1907	B. L. Glascock.
9	do	do	do		do	do	Do.
10	do	do	Springs	Hynson Springs	do	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
11	Lamar	Blossom	Salt well	Well on Main Street	Eagle Ford	Apr. 7, 1908	R. B. Dole and M. G. Roberts.
12	do	do	Well	Dr. A. J. B. Beauchamp	Blossom	Feb. 9, 1907	Do.
13	do	do	do	Well on Main Street	Eagle Ford	do	Do.
14	do	do	Black well		do	Feb. 14, 1907	Do.
15	do	do	Well	J. C. Thompson	Blossom	Feb. 11, 1907	Do.
16	do	do	do	Ed. Arnold	do	Apr. 7, 1908	Do.
17	do	do	do	W. J. Wallace	do	Feb. 9, 1907	Do.
18	do	do	do	T. F. Hefner	do	Apr. 7, 1908	Do.
19	do	do	do	Cotton-yard well	do	do	Do.
20	do	do	do	J. W. Williams	do	do	Do.
21	do	do	do	A. P. Ball	do	do	Do.
22	do	Paris	Artificial Lake	City supply		Dec. 1, 1902	Kennicott Water Softener Co.
23	do	do	Wells	Frisco Plant	Blossom	Nov. 29, 1902	Do.
24	Marion	Jefferson	Well	J. M. DeWare	Wilcox	Sept. 19, 1907	B. L. Glascock.
25	Morris	Daingerfield	do	Joseph Bradfield	do	do	Do.
26	Red River	Clarksville	Seep cistern	B. F. Mason	Annona	Mar. 5, 1907	H. S. Spaulding.
27	do	do	Well	600-ft. well	Blossom	Mar. 5, 1907	Do.
28	Wood	Mineola	do	Mineola Light & Ice Co	Wilcox	Feb. 3, 1908	J. R. Bailey and A. M. McAfee.
29	do	do	do	City supply	do	do	Do.

	County.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
1	Bowie	78	9.1	1.0	7.1	3.8	38	2.3	.....	41	31	.....	39	230
2	.....do	16	.5	.....	11	.8	862		24	717	1.6	.....	1,134	2,271
3	.....do	48	2.3	.....	14	1.6	882		26	706	3.6	.....	1,152	2,333
4	Cass	21	12	4.9	4.9	4.4	3.4	2.7	.0	18	25	.0	5.2	86
5	.....do	23	12	.....	11	8.5	13	.....	.....	41	1.9	1.0	5.5	112
6	Delta	.....	.....	.....	38	3.5	57	.....	8.5	.....	17	.....	8.5	161
7	.....do	16	[a]2.7	.....	36	4.5	11	.....	60	.....	20	.....	9.1	.....
8	Harrison	24	.51	1.3	5.4	2.0	15		.0	6.1	24	.44	7.0	86
9	.....do	26	.26	1.7	32	11	33	4.3	4.8	171	86	4.9	20	347
10	.....do	78	40	10	9.8	16	11	5.4	.....	.....	239	.06	14	435
11	Lamar	49	.21	.....	542	91	542		.0	175	1,670	.....	703	3,788
12	.....do	48	.15	.....	510	88	530	35	.0	38	2,485	1.8	151	4,112
13	.....do	50	.2	.....	660	110	965	35	.0	78	1,935	.0	1,872	5,558
14	.....do	75	.6	8.3	485	113	720	42	.0	11	2,695	.2	328	4,694
15	.....do	18	.2	.....	265	28	208	61	.0	227	465	10	499	1,693
16	.....do	31	.08	.....	304	24	214		.0	179	767	.....	237	1,932
17	.....do	49	3.8	.....	460	128	890	27	.0	146	3,180	.3	79	5,078
18	.....do	84	.12	4.0	474	109	892		.0	3.5	3,247	.....	99	5,185
19	.....do	42	.04	.....	492	114	960		.0	106	3,241	.....	88	5,089
20	.....do	48	2.4	.....	472	44	660		.0	38	2,585	.....	40	3,984
21	.....do	16	.44	.....	44	2.9	55		.0	179	55	5.0	31	324
22	.....do	45	[a]2.7	.....	31	5.1	55	.....	35	.....	57	.....	70	.....
23	.....do	43	[a]1.5	.....	25	4.0	85	.....	35	.....	108	.....	66	.....
24	Marion	31	18	6.4	32	14	25		.0	80	79	1.3	20	297
25	Morris	18	.68	.7	62	1.5	394	1.0	17	518	2.1	2.6	319	1,032
26	Red River	11	Tr.	.....	80	9.2	98	.....	.0	194	96	16	103	5,288
27	.....do	9.6	.2	.....	6.4	3.5	304	.....	37	387	147	3.3	122	835
28	Wood	17	3	1.9	2.6	4.2	49	2.8	2.4	102	19	1.8	7.0	154
29	....do	26	.40	.42	8.0	8.6	404	33	31	485	10	.01	310	1,069

[a] Iron and aluminum oxides.

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O

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

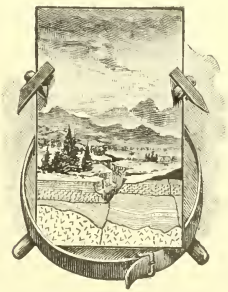
WATER-SUPPLY PAPER 277

GROUND WATER
IN
JUAB, MILLARD, AND IRON COUNTIES UTAH

BY

OSCAR E. MEINZER

IN COOPERATION WITH THE STATE OF UTAH
CALEB TANNER, STATE ENGINEER



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GROUND WATER IN JUAB, MILLARD, AND IRON COUNTIES, UTAH.

By Oscar E. Meinzer.

INTRODUCTION.

Location and extent of area.—Juab, Millard, and Iron counties lie in western Utah, and, with the exception of a small part of Iron County, are entirely within the Great Basin. (See fig. 1.) They comprise about 13,650 square miles, of which approximately 3,500 belong to Juab, 6,775 to Millard, and 3,375 to Iron County. Beaver County, which lies between Millard and Iron counties, is not discussed in this paper because its water resources have been described by W. T. Lee, of the United States Geological Survey, in Water-Supply Paper 217.

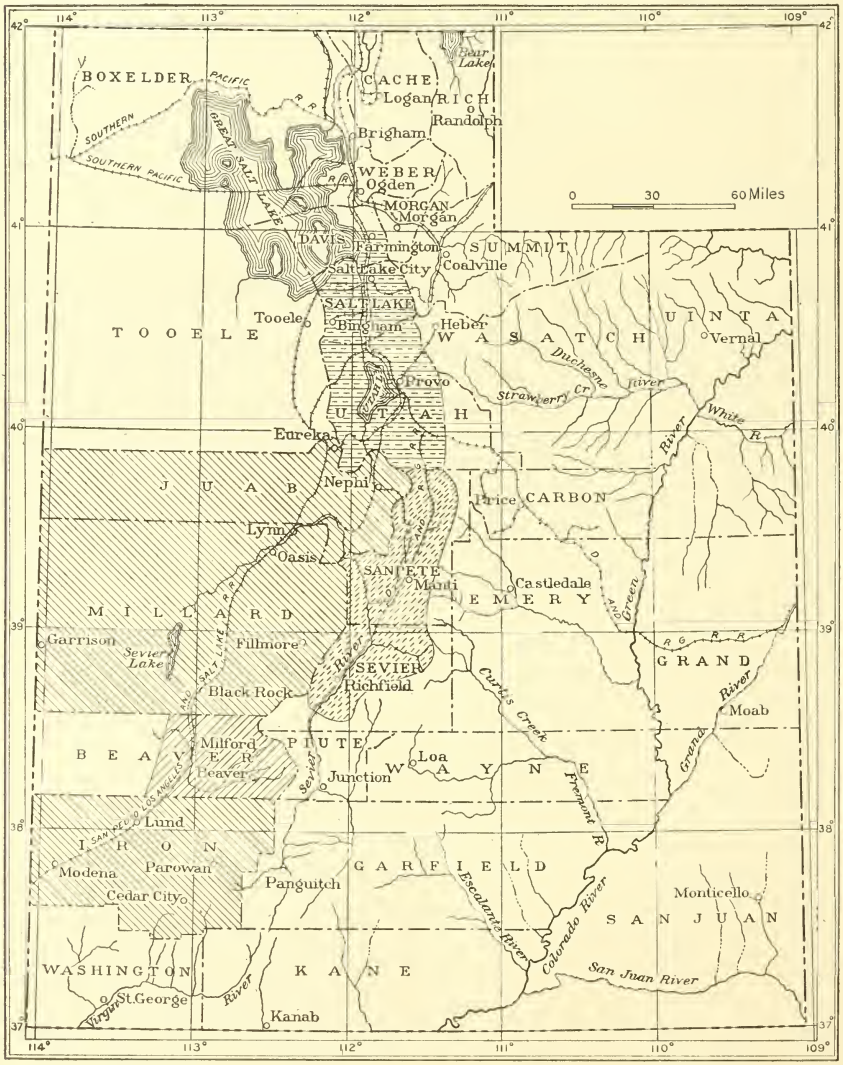
Purpose of investigation.—The investigation was begun in the summer of 1908, under cooperative agreement between the Director of the United States Geological Survey and Caleb Tanner, State engineer of Utah, the object of the work being to obtain and disseminate information which should lead to a greater utilization of the ground-water supplies.

The agricultural development of an arid section, such as this, is primarily dependent on the amount of water available. Large tracts of fertile soil remain idle year after year for lack of water for irrigation, while much water that falls as rain and snow sinks into the ground, saturates the porous materials underlying the valleys and deserts, and eventually reappears at the surface in low alkali flats, where it is dissipated by evaporation without producing useful vegetation. If the water thus lost can be applied to fertile soil it will substantially increase the agricultural yield of the region.

An urgent demand for information in regard to ground-water prospects has been created in recent years by the adoption of dry farming methods in localities where water is not readily obtained. The water required for culinary purposes and for supplying the horses and traction engines used in tilling the soil on some of the dry farms is at present hauled long distances.

In most of the arid parts of this region watering places of any sort are so scarce that certain sections are accessible for grazing only

in the winter when sheep will depend on snow for their water supply. In some of these sections an intelligent search would probably discover ground-water supplies which would increase greatly the value of the range.



Area covered in this report

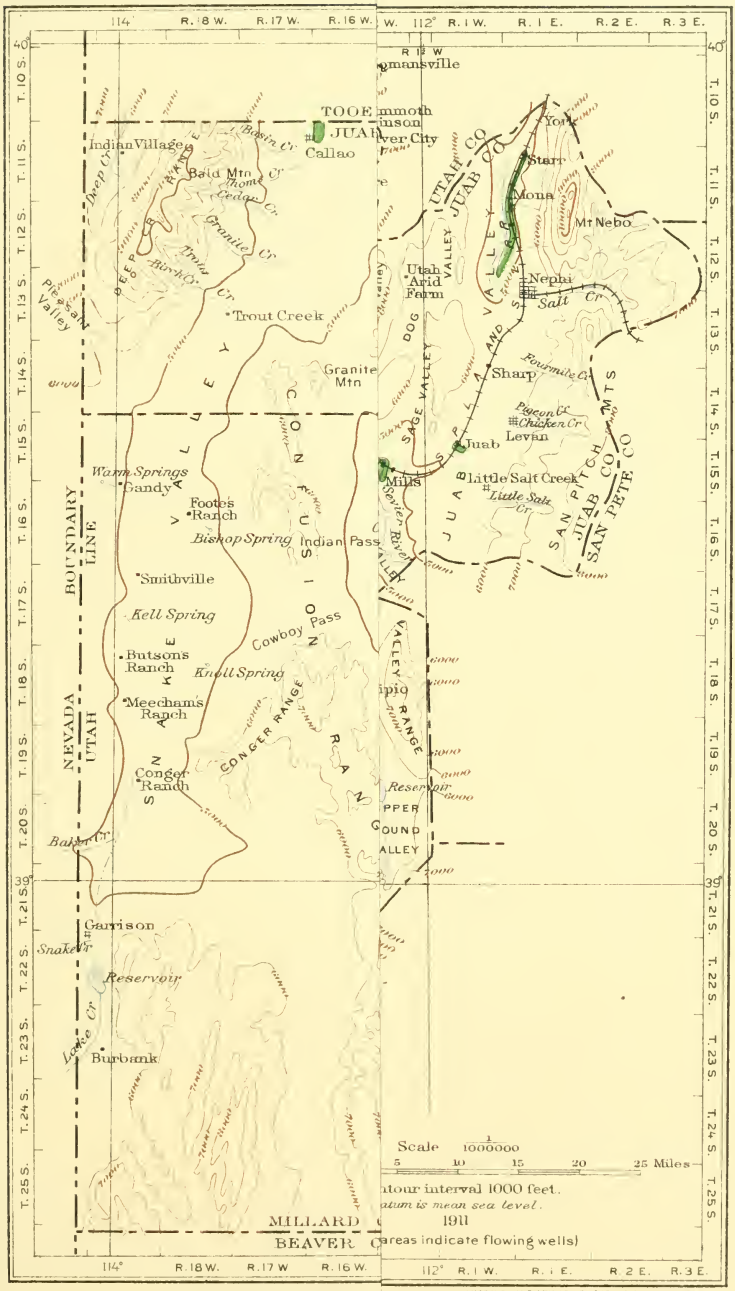
Area covered in Water Supply Paper 217

Area covered in Water Supply Paper 199

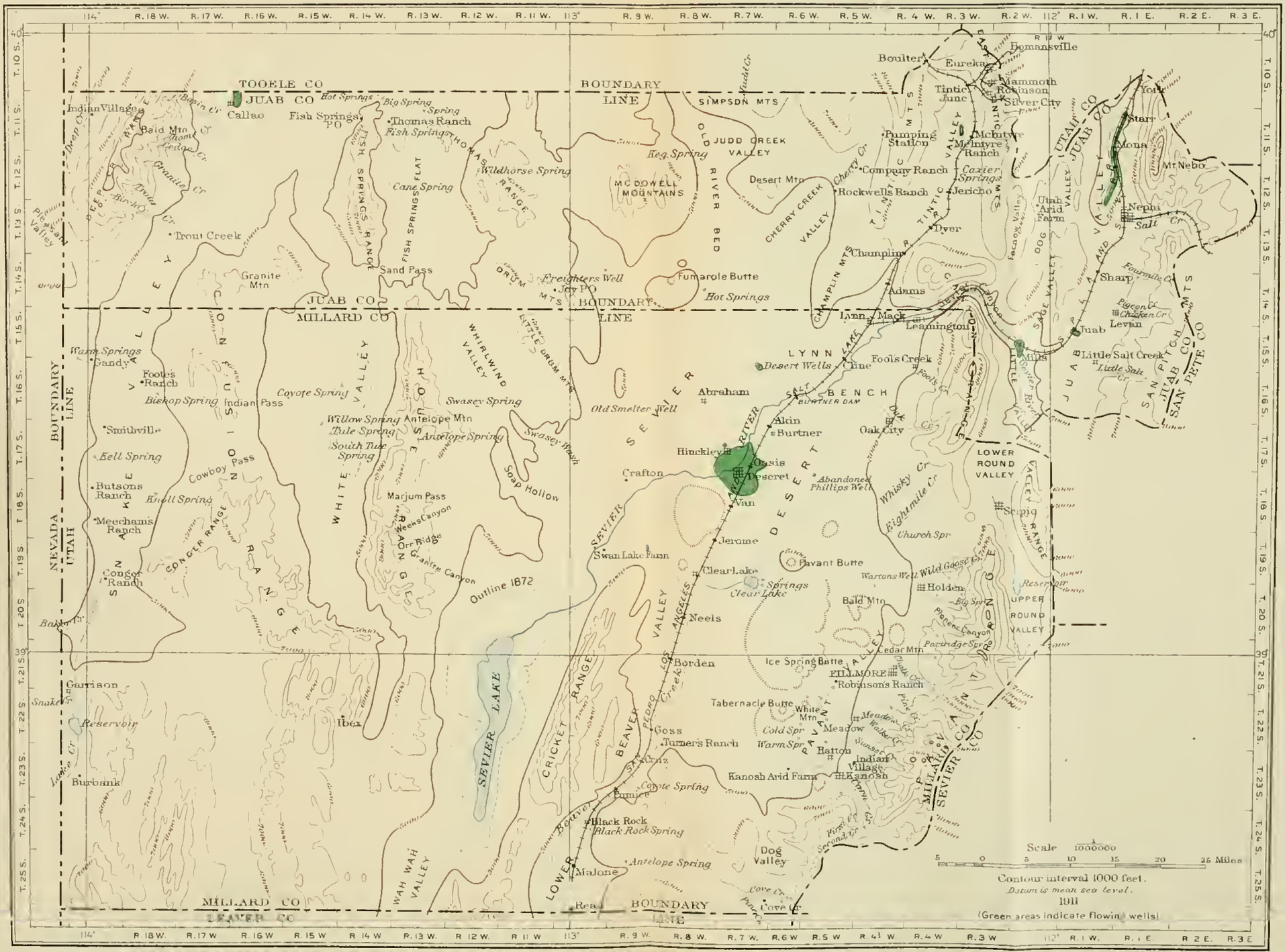
Area covered in Water Supply Paper 157

FIGURE 1.—Map of Utah, showing areas investigated.

Acknowledgments.—Valuable information was furnished by the San Pedro, Los Angeles & Salt Lake Railroad Co. in regard to deep railway wells; and four samples of water were analyzed by the State



TOPOGRAPHIC WING WELLS



TOPOGRAPHIC MAP OF JUAB AND MILLARD COUNTIES, UTAH, SHOWING AREAS OF FLOWING WELLS

Agricultural College at Logan, Utah. Thanks are also due to the inhabitants of the region for their hospitality and generous assistance.

PHYSIOGRAPHY.

UNITS OF DISCUSSION.

In dividing this region into units for convenience of discussion it has been found necessary to draw some rather arbitrary boundaries, to use names that have hitherto been known only locally, and to more definitely restrict recognized names than has heretofore been done.

The term "Sevier Desert" has long been used to designate a large and indefinitely bounded region; as used in this paper it refers to an area that is bounded on the north by the Juab-Millard County line, on the east by the Canyon Range, on the south by a line passing through Pavant Butte (Sugar Loaf Mountain) and the north end of the Cricket Mountains (Beaver Range), and on the west by the Little Drum Mountains, Swasey Wash, and the Long Ridge. The adjacent region north of the county line is here called the "Cherry Creek and River Bed region." The term "Pavant Valley," which in the past has been used vaguely, is here applied to the lowland tract which extends from Holden to Kanosh and is bounded on the east by the Pavant Range and on the west by Pavant Butte and the lava fields that extend southward from it. The name "Lower Beaver Valley" is used for the valley through which the channel of Beaver Creek passes, from Beaver County to Sevier Desert.

To that part of the valley of Sevier River which lies in Juab County between the Canyon Range and the northward extension of the Valley Range the name "Little Valley" is locally applied, and this name is used in this paper. For the tract extending from Sevier River to the "Dog Valley" in Juab County the name "Sage Valley" is used.

The term "Round Valley" has been applied to the upper valley of Ivie Creek, which contains the reservoir, and also to the lower valley, in which Scipio is situated. To avoid ambiguity, the expressions "Upper Round Valley" and "Lower Round Valley" are used in this paper.

PROVINCES.

Southwestern Utah belongs to two major physiographic provinces—the Plateau province and the Basin province. The former consists of nearly horizontal rock strata that have been lifted to a high altitude and deeply dissected by running water; the latter consists of a desert plain, several thousand feet lower, interrupted by more or less parallel and isolated mountain ranges which are as a

rule composed of rock strata that have been faulted and tilted. The boundary between these two provinces is an escarpment or series of escarpments, which, viewed from the Basin province, has the aspect of a lofty mountain range. The three counties here considered lie chiefly in the Basin province, and their eastern boundaries are in general formed by the escarpment of the Plateau province.

STREAM TOPOGRAPHY.

Superimposed on the grand features produced by the diastrophic forces that have lifted the plateaus and thrust up the Basin ranges are the features produced by running water. The temporary and permanent streams of the region are the agents in two complementary processes that give rise to two shaply contrasted types of topography. In their upper courses on the mountains and plateaus these streams have steep gradients and erode vigorously, thus cutting deep canyons and creating intricately carved surfaces; but in their lower courses—the low areas intervening between the mountain ranges—they are more sluggish, and their waters disappear by evaporation and downward percolation, thus depositing the sediments which they wrested from the mountains and building extensive gently sloping and featureless alluvial fans. Adjacent fans merge with each other to form broad, smooth, alluvial slopes that everywhere surround the rugged mountain ranges. The alluvial slopes of neighboring ranges extend toward each other, and the base of one may nearly touch the base of the other. The entire area between two ranges is in this region commonly called a "valley."

If there had been no weathering and no work had been done by the streams, the relief resulting from the deformation of the rocks would be much greater than it is. The plateaus and mountains would be higher; the basins would be lower. Ever since these topographic irregularities came into existence the streams have been at work obliterating them by tearing down the mountains and filling the intervening basins. The extent to which the basins have thus been filled is known definitely at only a few points where wells of unusual depth have been sunk, but in many places this filling is probably very deep.

LAKE TOPOGRAPHY.

Superimposed on the surface molded by running water are strikingly different features produced by the waters of an ancient lake. Along the shores of this ancient lake were formed cliffs, terraces, beach ridges, bars, spits, and deltas such as exist along the shores of modern lakes. Shore features were formed at every level at which the lake stood for some time, but they are the most prominent at two levels known as the Bonneville and Provo levels. (See p. 18.) They

have a horizontal arrangement which attracts attention by its contrast with the oblique lines produced by stream work.

Since the desiccation of the ancient lake few important topographic changes have taken place. The low areas are still undergoing aggradation rather than degradation, but the upper parts of the alluvial slopes are in some places being subjected to stream erosion.

WIND TOPOGRAPHY.

Wind work has been most effective in rehandling the sand that was washed by the waves upon the shores of the ancient lake. The storm winds at the time the lake was in existence seem to have been prevailingly from the west, as they are at the present time, and the largest accumulations of sand were consequently made on the eastern shore, where they have given rise to many dunes, especially in the area between Cherry Creek and Holden.

In the White Valley wind erosion has produced a fantastic hummocky topography (see p. 122), and in Snake Valley the wind has helped to build large knolls about some of the principal springs (see pp. 44–45).

MINOR BASINS.

The Basin province contains a number of distinct and independent drainage systems that are separated from each other by divides formed by rocky ridges or low accumulations of alluvium. If a valley has an abundant water supply it may have an outlet through which its streams discharge either continuously or at times of flood. Thus the north basin of Juab Valley discharges into Utah Valley, which discharges into Great Salt Lake. Thus the south basin of Juab Valley discharges into Little Valley and thence, through Sevier River, into Sevier Lake. Thus, too, at times of high water a part of Rush Lake Valley discharges into Escalante Desert. But where the water supply is meager or other conditions are less favorable, overflow does not take place and the basin has a closed drainage. Such basins are formed, for example, by Pàrowan Valley, White Valley, and Lower Round Valley.

The outlets of some of the valleys consist of canyons cut through rock walls, as, for example, Sevier Canyon, which leads from Little Valley to Sevier Desert; the canyon of Currant Creek, which forms the outlet of the northern part of Juab Valley; and the canyon of Chicken Creek, which forms the outlet of the southern part of Juab Valley. Some of these canyons do not occur at the lowest parts of the inclosing rim, but have been cut boldly through higher mountainous parts. They appear to be the work of streams which flowed before the rock barriers were thrown up and which persisted in their

courses during the deformation by cutting down their channels as rapidly as the rocks were lifted.

Hieroglyph Canyon, which is cut through the barrier between Parowan and Rush Lake valleys, and the channel that leads from Lower Round Valley to Little Valley were both obviously formed by running water, though they are no longer occupied by streams, even in times of flood. In some of the other outlets the streams are so small and intermittent that they could scarcely have produced the canyons which they occupy. Doubtless when the climate was sufficiently humid to produce the large ancient lake all these gorges were traversed by vigorous streams, but the date of their origin seems to be earlier.

The north basin of Juab Valley, a part of the Old River Bed region, the region north and northwest of the McDowell Mountains, Fish Springs Valley, and a part of Snake Valley belong to the Great Salt Lake drainage basin. The south basin of Juab Valley, Little Valley, Tintic Valley and its mountain borders, a part of Sevier Desert, Lower Beaver Valley, a part of Wah Wah Valley and some of the high area farther west, and the Swasey Wash region belong to the Sevier Lake drainage. White Valley and Round Valley each forms a closed drainage basin; Snake Valley contains several rather distinct drainage basins; and Sevier Desert, though nearly flat, contains several depressions which are more or less independent of each other. Thus the swampy area in the vicinity of the Hot Springs north of Abraham does not normally drain into Sevier Lake, and the same seems to be true of certain ponds and swamps near Pavant Butte, of the swampy tract west of Holden, of Chalk Creek Sink, and of the bottoms farther south.

Parowan Valley, Escalante Desert, and parts of Rush Lake Valley form independent drainage basins, but a part of Rush Lake Valley is more or less tributary to Escalante Desert.

The large number of independent basins is a result of arid conditions. In the dry seasons a drainage system becomes dismembered, the water from different parts terminating in insignificant local depressions; when more humid conditions return, these local depressions quickly fill with water and overflow, thus reuniting the drainage from different parts into a single system. In the past the overflowing and uniting process continued until practically all of this area discharged its waters into the ancient lake, and hence belonged to a single drainage basin. At last the ancient lake itself overflowed (pp. 16–18) and for a time the entire region became tributary to the Pacific Ocean. If humid conditions had continued long enough, the outlet would have been cut so low that the lake would have been drained completely, and by a similar process the minor depressions would also have been drained.

GEOLOGY.[1]

FORMATIONS.

The rocks exposed in the large area here considered probably range in age from pre-Cambrian to Recent.

The rocks supposed to be pre-Cambrian consist mainly of granite and are found in only a few localities.

The Paleozoic formations include a great thickness of apparently conformable beds which consist chiefly of quartzites and indurated dark-gray limestones of Cambrian and Carboniferous age. The Basin ranges are composed of these rocks.

Above the quartzites and limestones are several thousand feet of highly colored clastic beds which belong to the Permian series of the Carboniferous, and to the Triassic and Jurassic systems. They are best exposed in the plateau in eastern Iron County, but are not confined to this region. Above the Jurassic is a succession of Upper Cretaceous shales and sandstones, which have a grayish appearance and aggregate several thousand feet in thickness. Like the Jurassic, they are best developed in eastern Iron County, but are also found farther north. Beds of gypsum occur in the Jurassic and coal in the Cretaceous.

At higher horizons are found early Tertiary conglomerates, sandstones, shales, and limestones of nonmarine origin. In Iron County they rest on the Cretaceous beds; but in the Canyon Range, in parts of the Pavant Range, and in the low ridges east of these, sandstones and conglomerates presumably of Tertiary age rest with a pronounced unconformity on Paleozoic quartzites and limestones.

Stream, lake, and wind deposits, consisting of relatively unconsolidated gravel, sand, and clay, occur to great depths beneath the valleys and low desert tracts. These sediments were the last to be deposited and are late Tertiary, Pleistocene, and Recent in age. As there are few outcrops the relative importance of stream and lake sediments is largely a matter of conjecture. At the foot of the lofty mountains and plateaus in the eastern part of this region stream deposits and coarse beach and delta deposits of local origin predominate, but far out in the deserts fine-grained lake sediments are present in large quantities. The smaller Basin ranges furnish only meager amounts of rock waste. In some places, as at the north end of Fish Springs Range, they are partly buried beneath the lake flat and are nearly devoid of alluvial slopes. The Neels and Goss railroad wells, in Lower Beaver Valley, are near the Cricket Mountains, yet they reveal sections consisting almost exclusively of fine sediments

[1] The brief sketch here given is chiefly summarized from the works of the geologists who have studied the region, especially the Geology of the High Plateaus of Utah, by C. E. Dutton: U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

such as would settle to the bottom of a lake at some distance from the shore from which they are derived. (See pp. 98–100 and Pl. III.)

Volcanic rocks are widely distributed over this region. They are all or nearly all younger than the early Tertiary strata, upon which they rest in many places. They belong chiefly to the later epochs of the Tertiary period, but are in part coeval with the ancient lake and in part still more recent.

GEOLOGIC HISTORY.

Paleozoic formations containing marine fossils occur generally in this region, and it is therefore certain that during at least a part of the Paleozoic era the region was covered by the sea. Mesozoic and Tertiary formations are strongly developed in the plateaus and in some of the ranges near the Plateau province, but they are absent over most of the Basin province. It has therefore been inferred that most of the Basin province emerged from the sea before the Mesozoic and Tertiary sediments were deposited.

Throughout the Basin province the Paleozoic formations have been faulted and tilted to produce the Basin ranges. It is not known at what time these faulting movements began, but fresh scarps on the alluvial slopes of some of the ranges, as, for example, in the vicinity of Fish Springs,[1] show that they are still in progress.

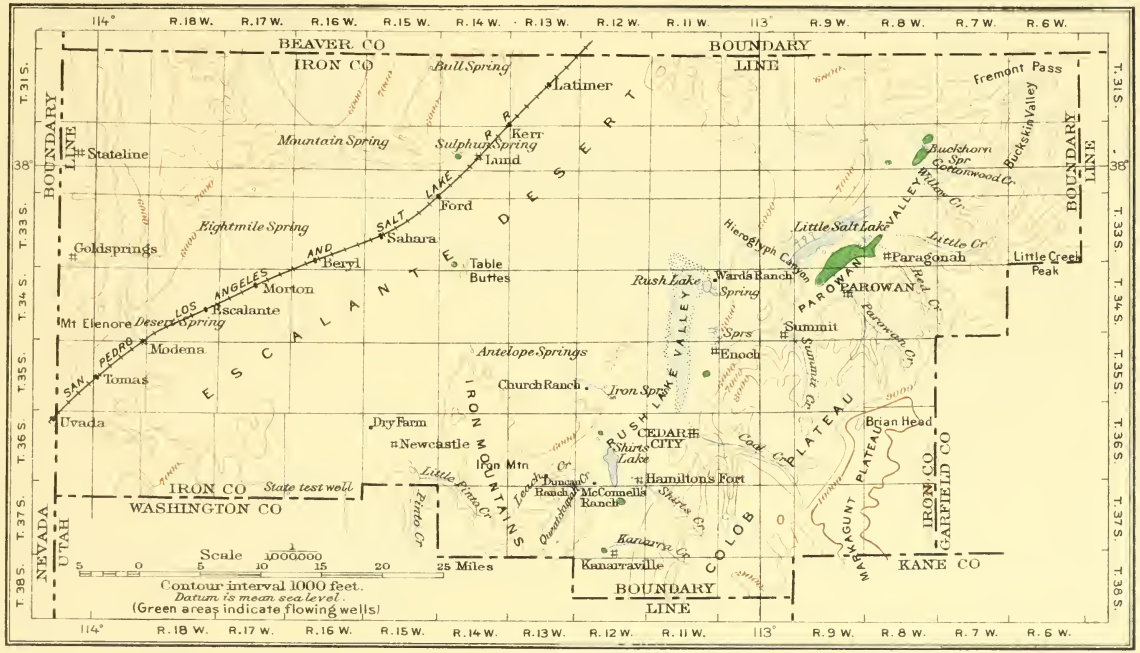
In the Colob Plateau, in eastern Iron County, the great thickness of Permian and Mesozoic strata that intervenes between the earlier Carboniferous and Tertiary rocks indicates sedimentation during much of the interval which they represent, but the fact that in the Canyon Range and adjacent mountains Tertiary deposits rest directly on the eroded and irregular surface of the early Carboniferous or the older Paleozoic rocks indicates that erosion was here taking place during much of the time that sedimentation was in progress in the Colob Plateau region.

After the early Tertiary sediments had been deposited the Plateau province was lifted bodily with reference to the Basin province, thus producing the escarpments that form the boundary between these two provinces. This relation is best shown in Iron County, where the tabular, though greatly dissected, Markagunt and Colob plateaus tower above the basins and low ranges to the west, separated from them by a profound fault and an imposing fault scarp known as the Hurricane Ledge. Farther north the boundary between the two provinces is less definite. The Pavant Range and the mountain mass east of Juab Valley have some of the characteristics of each province.

In the Pleistocene epoch western Utah contained a large lake, which has been fully described by G. K. Gilbert,[2] who named it Lake

[1] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 353.

[2] Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890. The description of Lake Bonneville in this paper is largely abstracted from Mr. Gilbert's monograph.



ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

TOPOGRAPHIC MAP OF IRON COUNTY, UTAH, SHOWING AREAS OF FLOWING WELLS

1911

Bonneville.[1] At the time of its maximum extent this lake covered an area of 19,750 square miles and was 346 miles long, measured in a straight line, 145 miles wide, and 1,050 feet in maximum depth. Its surface was about 5,200 feet above the present sea level, or about

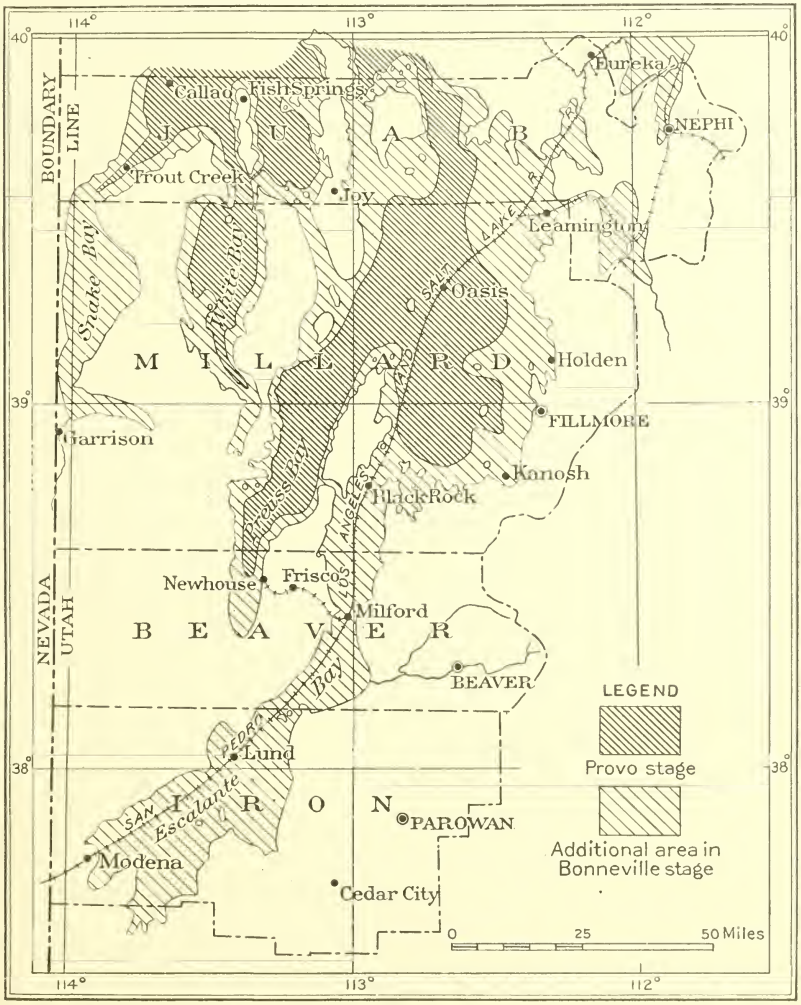


FIGURE 2.—Map of Juab, Millard, Beaver, and Iron counties, Utah, showing areas covered by Lake Bonneville. (After G. K. Gilbert, Mon. U. S. Geol. Survey, vol. 1, 1890.)

1,000 feet above the present level of Great Salt Lake. Its shore line had many irregularities, and, exclusive of the islands, had a total length of about 2,550 miles. Promontories, peninsulas, islands, bays, and straits existed in abundance, for the Basin ranges were con-

[1] U. S. Geog. and Geol. Surveys W. 100th Mer. [Wheeler Survey], vol. 2, 1875, p. 88.

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verted into rocky peninsulas and islands, and the intervening low areas into bays and straits.

The main body of Lake Bonneville was north of Juab County, covering Great Salt Lake Desert, but at its highest stage approximately 5,000 square miles, or one-fourth of its total area, lay within the three counties here considered. If the lake existed at present Deseret would be covered by 600 feet of water; Nephi, Oak City, Holden, Fillmore, and Kanosh would be at or near the shore, while Joy and Utah Mine would be situated on islands. The outline of the lake when it stood highest (known as the Bonneville stage) is shown in figure 2.

When the lake reached the Bonneville stage it found an outlet toward the north at a point where several hundred feet of uncemented alluvium rested on indurated limestone. The outflowing stream rapidly swept away the alluvium and as rapidly lowered the lake level; but when it reached the limestone downward cutting progressed very slowly and the lake consequently stood at virtually one level for a long period. This long period is known as the Provo stage, and the prominent shore line formed at this time is known as the Provo shore line. At the Provo stage the lake stood about 375 feet lower than at the Bonneville stage, but it still covered a large part of Sevier Desert, Fish Springs Valley, and White Valley, as is shown in figure 2. Eventually, when more arid conditions returned, the lake fell below the level of its outlet and shrank little by little until it dwindled to its present insignificant dimensions. More or less distinct shore lines were formed at a number of levels, but the two that can generally be recognized in the area here considered, and that are significant in discussing ground water conditions, are those that mark the Bonneville and Provo levels.

Volcanic activity began on a grand scale in the Tertiary period and has continued almost to the present day. Some of the lava was extruded so recently that it remains almost untouched by the weather.

RAINFALL.

GEOGRAPHIC DISTRIBUTION.

Rainfall observations have been made for the United States Weather Bureau at the stations in Juab, Millard, and Iron counties as shown in the following table.

Rainfall data are comparatively abundant for the belt adjacent to the Plateau province, but are meager for the large desert area comprising the greater part of these counties, and are entirely wanting for the lofty mountain regions.

Precipitation (in inches) in Juab, Millard, and Iron counties, Utah.

Years.	Station.						
	Nephi.	Levan.	Scipio.	Oak City.	Fillmore.	Black Rock.	Deseret.
1891							
1892							9.47
1893		15.75			15.59		7.66
1894		17.73			13.37		8.01
1895		26.12			16.36		
1896		12.37	13.62		11.16		
1897		16.79	19.24		17.04		
1898		15.67			14.59		
1899		17.43	15.52		14.48		
1900		10.34	6.92		9.32		5.38
1901		13.31	12.69		12.88	7.61	9.01
1902		12.49	11.75		11.90	6.38	4.85
1903		12.58	11.01		11.97	13.36	6.99
1904		16.26	12.58		12.14	6.39	7.14
1905	14.62	16.24	21.13		16.16		9.76
1906	22.34	23.84	19.99	19.05	21.28		11.77
1907	18.00	20.09	18.03	14.24	17.14		9.64
1908	16.84	18.22	15.97		18.43		
Average		16.58	14.87		14.61	8.43	8.15

Years.	Station.					
	Callao and Trout Creek.[1]	Garrison.	Parowan.	Cedar City.	Lund and Enterprise.[2]	Modena.
1891			14.24			
1892			11.00			
1893			12.80			
1894			12.97			
1895			12.07			
1896			9.17			
1897			18.47			
1898			13.82			
1899			10.92			
1900			7.04			
1901			11.05			9.24
1902			9.02			5.09
1903		4.75	11.89		9.36	6.93
1904	7.77	7.21	11.32			9.83
1905		8.82	13.47			12.39
1906	12.34		20.87			19.06
1907	8.28	4.35	13.73	16.16		12.80
1908			11.80	13.73	16.97	16.62
Average		6.28	12.54			11.50

[1] Callao in 1904; Trout Creek in 1906 and 1907.

[2] Lund in 1903; Enterprise in 1908.

These records show the heaviest rainfall in the valleys at the foot of the lofty mountains and plateaus along the east margin of the region and much lighter rainfall in the extensive desert area to the west. Thus the average annual precipitation is 16.58 inches at Levan, 14.87 inches at Scipio, and 14.61 inches at Fillmore, but only 8.15 and 8.43 inches, respectively, at Deseret and Black Rock, and only 6.28 inches at Garrison. Apparently the semiarid conditions found at Levan, Scipio, and Fillmore exist over a relatively small area, while the truly arid climate indicated at Deseret, Black Rock, and Garrison prevails over the greater part of the region.

Though no observations are recorded for the lofty mountains and plateaus, the character of their forests and other vegetation makes it

evident that they have more precipitation than the lowlands. This is true of the Wasatch Mountains, the San Pitch Mountains, and the Canyon and Pavant ranges, in eastern Juab and Millard counties;

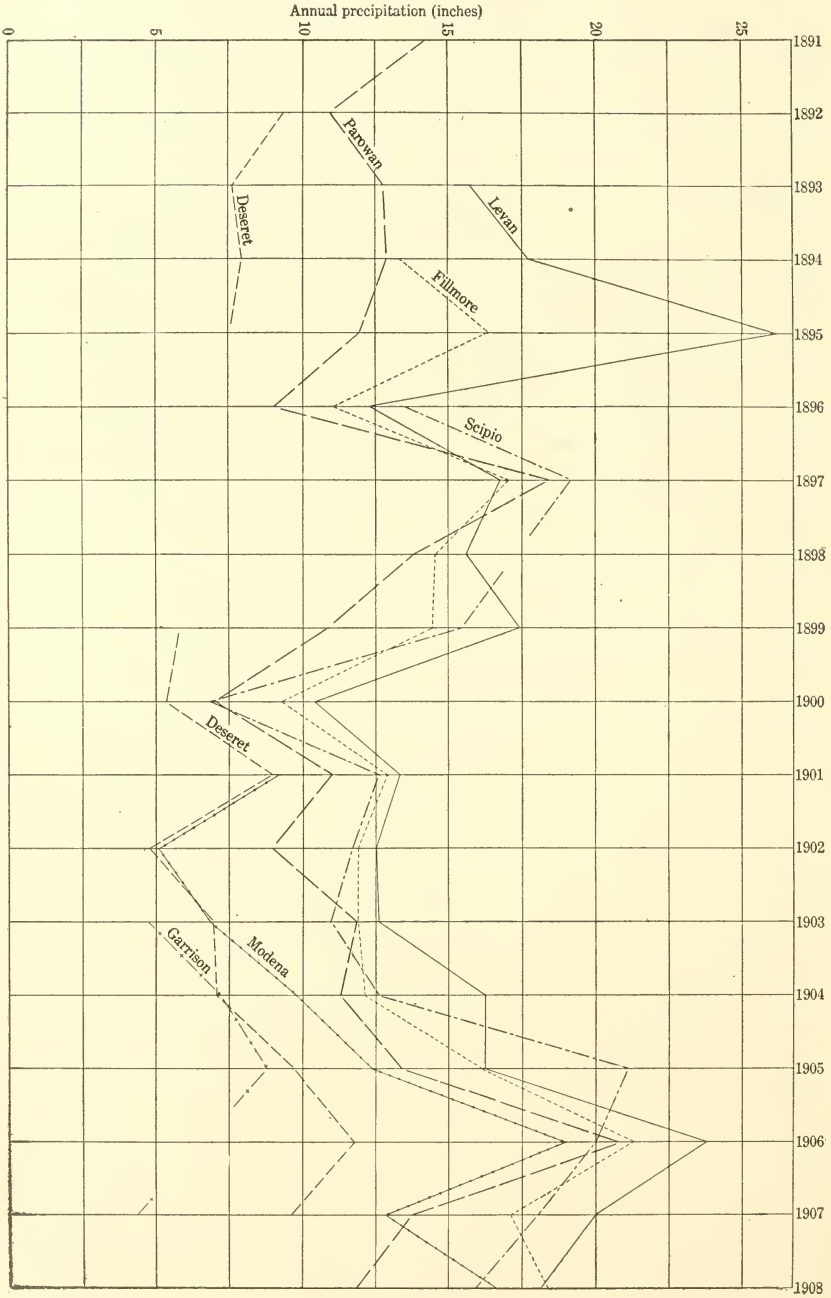


FIGURE 3.—Diagram showing annual precipitation at stations in Juab, Millard, and Iron counties, Utah.

of the Colob and Markagunt plateaus, in eastern Iron County; of the Deep Creek Range, in western Juab County; and to some extent of the West Tintic and other mountains. But the dry and barren condition of most of the low Basin ranges indicates that these ranges receive little more rainfall than the surrounding desert.

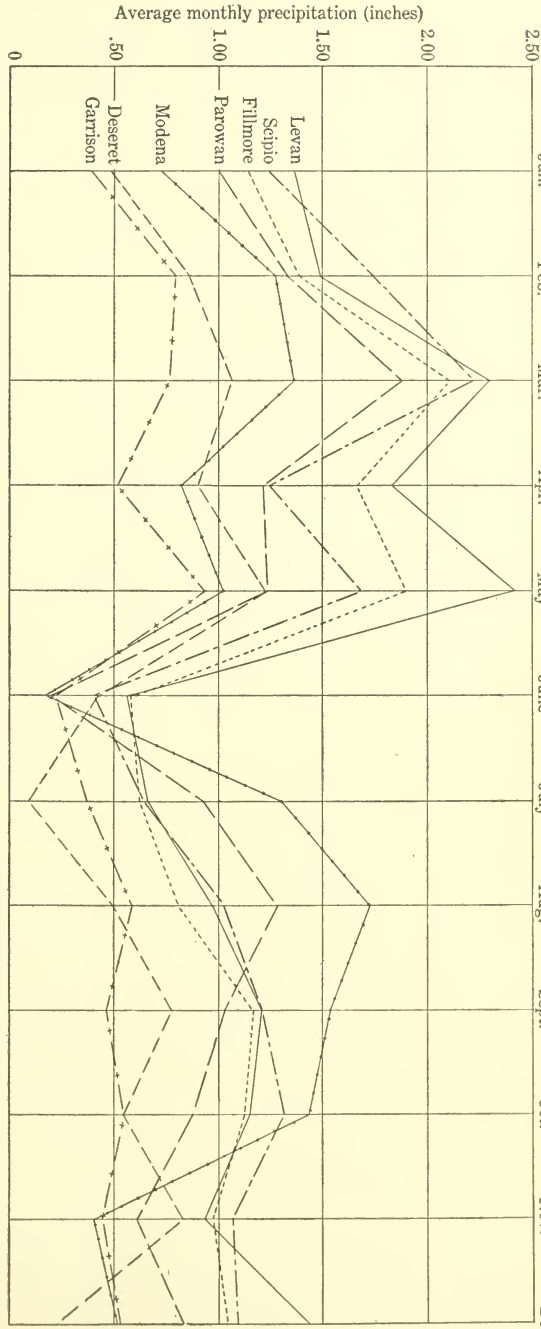


FIGURE 4.—Diagram showing average monthly precipitation at stations in Juab, Millard, and Iron Counties, Utah.

ANNUAL VARIATION.

The precipitation varies greatly from year to year. Thus the recorded range is between 26.12 and 10.34 inches at Levan, between 21.13 and 6.92 inches at Scipio, between 21.28 and 9.32 inches at Fillmore, between 11.77 and 4.85 inches at Desert, between 20.87 and 7.04 inches at Parowan, and between 19.06 and 5.09 inches at Modena.

In general these variations are regional rather than local, as shown by figure 3, in which there appears a general agreement between the curves of the different stations. At all stations where observations were made the precipitation in 1900 was

below the average, and at all but one it was the lowest recorded. In 1906 the precipitation was everywhere above the average, and at all but two stations it was the highest ever recorded. For the region as a whole, the precipitation was below the average in 1896 and above the average in 1897, after which it decreased each year until 1900. From 1901 to 1904 it was somewhat higher than in 1900, but still below the average. In 1905 it was slightly above the average; in 1906 it was exceptionally high; and in 1907 and 1908 it was somewhat lower than in 1906, but still well above the average.

Though the variations from year to year are for the most part regional, yet some remarkable local variations occur, as for example, in 1903 the rainfall at Black Rock was heavier than at Levan or any other station.

SEASONAL VARIATION.

The precipitation is distributed unequally through the year, as is shown by figure 4, in which, for each station having a sufficiently long record, the average for each month is represented. In Juab and Millard counties the most rain falls in the months of March, April, and May, and the least in June and July. In Iron County (Parowan and Modena) the distribution is somewhat different, the spring rainfall being relatively less and the late summer rainfall distinctly greater. In this respect climatic conditions in Iron County to some extent resemble those in New Mexico and Arizona, where the principal rainy season is in the latter part of the summer.[1]

RELATION OF RAINFALL TO DRY FARMING.

Until recently farmers have relied almost entirely on irrigation, but in the last few years many attempts have been made to raise crops without artificial application of water. Dry farms conducted on a large scale have been established in Juab, Dog, Little, and Pavant valleys, and in the southeastern part of Escalante Desert, and dry farming on a smaller scale has been undertaken in the other valleys along the east side of the region, and even in the vicinity of Deseret and at Ibex, west of Sevier Lake. In Juab Valley good crops of wheat have been raised without irrigation;[2] in the other localities dry farming was still largely in the experimental stage in 1908, when the region was visited. The weather data show that Levan, in Juab Valley, receives a little more rainfall than the stations in the other valleys along the east side, and much more than those in the desert to the west. They also show that the region in

[1] Henry, A. J., Climatology of the United States: U. S. Weather Bureau, Bull. Q, 1906, p. 50.

[2] See Farrell, F. D., Dry-land grains in the Great Basin: Circular 61, Bur. Plant Industry, U. S. Dept. Agr., 1910.

general received more than an average amount of rainfall during 1906, 1907, and 1908.

SOIL.

This region contains much more arable land than can be irrigated with the supply of water that is now available or that would be available if all the water resources were fully developed and conserved. Nevertheless, the arable land comprises only a fraction of the total area. It does not include the mountain regions, the lava fields, the gravelly upper portions of the alluvial slopes or bench lands, the sandy dune-covered belts, nor the low, swampy tracts. The best agricultural land is found on the middle portions of the alluvial slopes, below the zone of the coarse gravel and above the alkali.

The soil of the low tracts is almost everywhere impregnated with harmful quantities of alkali. The surface water coming from the higher regions accumulates in these low tracts and the water that sinks into the ground on the higher lands returns to the surface here, both to be disposed of by evaporation. In their contact with the earth both surface and ground waters take up small quantities of soluble mineral matter (alkalies), which they leave behind when they evaporate. Hence, by a slow but long-continued process the soluble substances disseminated through the soil and rocks of the upland regions become concentrated in the lowlands until they exist in amounts injurious to ordinary plants.

The character of the vegetation and in many places the incrustations at the surface show that the low central axes of nearly all the valleys and the extensive low flats of Great Salt Lake Desert, Sevier Desert, and Escalante Desert have alkali soils. Even in valleys that have outlets, such as Juab Valley, Little Valley, and parts of Rush Lake Valley, the discharge is so sluggish and (except in Little Valley) so intermittent and the evaporation is comparatively so great that alkali has accumulated. The largest tracts of alkali soil are the desert flats which for a long time were covered by the waters of a salt lake and which lie so low that in some places the ground water still comes to the surface and evaporates. In the detailed descriptions of Sevier Desert, Wah Wah Valley, and Escalante Desert analyses of soil from several localities are given. (See pp. 109–110, 118, and 150–151.)

The fertile land in most localities lies so high that some of the water available for irrigation can not be brought to it without pumping. In order to utilize this water, low land is cultivated and consequently the presence of alkali becomes a source of trouble. This trouble is perhaps greatest on the low flat in the vicinity of Deseret, where water from Sevier River is used. Two remedies are here available, both of which are now under consideration. One is to install a drainage system, by means of which the alkali can be

washed out of the soil; the other is to divert the water so far upstream that it can be conducted by gravity to higher and better land.

Outside of Sevier Desert the principal difficulties with alkali are experienced where irrigation is attempted with water from springs or wells. A number of large springs in Snake Valley and Fish Springs Valley, the large springs near Clear Lake, and many smaller springs and seeps in Pavant and other valleys are used for irrigation, but the crops produced are insignificant when compared with the amount of water applied, the difficulty being that the water issues at low levels, where the soil contains alkali. Likewise nearly all the wells in which the water rises to the surface or nearly to the surface are on low ground, and irrigation with well water is generally accompanied by trouble with alkali.

VEGETATION.

The native vegetation is an index to the character of the soil and climate of the region.

The mountains and plateaus that are high enough to receive a copious fall of rain and snow are covered with forests of yellow pine, fir, quaking asp, birch, maple, cottonwood, scrub oak, and other trees and shrubs; but the arid Basin ranges and volcanic buttes and mesas support few trees, except stunted conifers such as scrub cedar, juniper, and piñon pine, and the broad valleys and deserts are treeless, except for clumps of cedar and piñon on the upper parts of some of the alluvial slopes, a few dwarfed willows in the vicinity of springs, and cottonwoods or other species planted in the irrigated oases.

On the alluvial slopes of the valleys in the eastern part of these counties, large and luxuriant sagebrush (*Artemisia tridentata*) predominates, and along dry runs, where it receives a comparatively plentiful water supply, without being subjected to alkali or swampy conditions, this brush grows to treelike proportions.

Farther west the more arid climate is clearly reflected in the more scanty vegetation, the large sagebrush being replaced by stunted individuals and by smaller species. Here the bush known as shadscale becomes common, and in many localities it is dominant.

In extensive low tracts, where the climate is arid and the soil contains alkali, but where the ground water is near the surface, greasewood is present almost to the exclusion of other plants. Under favorable conditions the greasewood rivals in size the most luxuriant sagebrush, and where it is well watered its rich green aspect contrasts strongly with the monotonous grayish-green hue which the sage and shadscale give to most of this country. In localities where there is some natural irrigation but where the soil does not contain excessive quantities of alkali greasewood may be supplanted by rabbit brush: in areas having an alkali soil, but greater depth to water, it is likely

to give way to shadscale; and in swampy districts heavily impregnated with alkali it yields to saltbrush.

Forage grasses grow on the well-watered mountains and plateaus and in meager quantities on the more arid Basin ranges and in the valleys and deserts. Swampy areas watered by springs and seeps may produce a large growth of grass, which, however, is poor in quality. Some forage is also supplied by a small plant locally known as black sage and by greasewood and other bushes. The entire region is placed under tribute for grazing, though the number of acres necessary to feed one animal is large. Horses and cattle are raised, but most of the range, especially the driest part, is used for sheep. In the summer most of the sheep are kept on the high plateaus, but in the winter they are brought into the desert.

Cacti occur in this region, but are not abundant. They are found in the largest numbers in southern Iron County. Tules or other rushes grow at the margins of some of the springs, and water-cress thrives in the large springs and their effluent streams, especially in Snake Valley. The Hot Springs near Fish Springs and the Hot Springs in the River Bed region support filimentary algæ of various colors.

In the low parts of some of the deserts and valleys there are extensive alkali clay flats that are destitute of vegetation of any kind. These flats remain intensely dry for long periods, but are occasionally inundated, and it seems that none of the desert plants can adapt themselves to such extremes.

STREAMS.

Sevier River is the only large stream that enters this region. It rises on the plateaus of Iron and Kane counties and flows northward a long distance through a structural trough that lies just beyond the eastern boundary of Iron, Beaver, and Millard counties. Eventually it turns to the west, crosses into Juab County, traverses Little Valley, and escapes through Sevier Canyon, at Leamington, into the desert, across which it meanders to Sevier Lake. Much of the water is diverted for irrigation before the river reaches the region described in this paper, but a part is used by the settlements in Sevier Desert and a part still escapes into Sevier Lake, where it evaporates.

Many small disconnected streams rise in the highlands along the eastern border of these counties, descend with steep gradients through rock-bound canyons, and emerge on the arable alluvial slopes, where their waters are used for irrigation. During the spring months they are supplied largely by the melting of snow at high altitudes and their flow is therefore relatively copious. Later in the season, when all or nearly all of the snow has disappeared, they shrink greatly and the smallest creeks become dry. The streams that

head in the highest mountains are fed from melting snow until late in the summer, but those that drain less lofty ranges and plateaus dwindle long before the crops mature. Heavy rains may fall at any time and give rise to swollen, torrential streams that rush down the canyons and across the alluvial slopes. If storage facilities could be provided whereby the flow of these streams could be controlled and the water they discharge each year could be applied to crops when needed, much more land could be irrigated. Unfortunately neither the narrow canyons with their steep grades nor the open alluvial slopes afford good reservoir sites, and little has been accomplished in the way of storing water.

The areas receiving these small mountain streams are Juab Valley, in Juab County, Round Valley and the areas west of the Canyon and Pavant ranges, in Millard County, and Parowan and Rush Lake valleys, in Iron County. The Wasatch Mountains and San Pitch Mountains give rise to streams that flow into Juab Valley, the largest of these being Salt Creek, which emerges at Nephi. The Canyon Range is drained chiefly toward the west and on the west side rise several streams, the largest of which is Oak Creek. The west flank of the Pavant Range is drained by numerous streams, among which Chalk Creek and Corn Creek are the largest. The streams originating on its east flank all flow into Sevier Valley, except Ivie Creek, which rises at the head of Upper Round Valley and furnishes the irrigation water at Scipio. The high plateau in eastern Iron County gives rise to a series of streams that discharge into Parowan and Rush Lake valleys, the largest being Parowan Creek and Coal Creek. Further statements in regard to these streams will be found in the detailed descriptions.

In the remaining parts of these three counties there are only a few small streams. In Juab County, Cherry Creek, Judd Creek, and several still smaller streams rise in the West Tintic and Simpson mountains, and a number of creeks flow from both sides of the Deep Creek Range, but in the area intervening between the Simpson and Deep Creek mountains, covering a stretch fully 50 miles long, there are no streams except such as flow from the Fish Springs. In Millard County the only streams between Sevier River and the Nevada line are a few creeks that flow into Snake Valley from the west. The highlands south of Iron County give rise to Shoal, Meadow, and Pinto creeks, which flow toward Escalante Desert, and the Iron Mountains give rise to several small creeks, but the entire north-central and northwestern sections of Iron County are destitute of streams.

INDUSTRIAL DEVELOPMENT.

The region under consideration supports a population of about 20,000 people, or approximately 1½ persons per square mile. But the

geographic controls of human existence and industrial development are so rigorous that the inhabitants are very unequally distributed, and any statement of average density of population has little significance. The two important controlling factors are (1) water for irrigation and (2) ore deposits.

Most of the inhabitants live at the foot of the highlands along the east margin of the region and depend on the numerous small streams that issue from these highlands. There is a settlement at the mouth of nearly every canyon that has a stream, and the size of the stream is a good index to the size of the settlement, or vice versa. Relatively large streams, such as Salt Creek, Chalk Creek, Corn Creek, Parowan Creek, and Coal Creek, support large settlements, such as Nephi, Fillmore, Kanosh, Parowan, and Cedar. Smaller streams, such as Oak Creek, Summit Creek, Shirts Creek, and Kanarra Creek, support smaller settlements, such as Oak City, Summit, Hamiltons Fort, and Kanarraville. Very small streams, such as Little Salt Creek, Fools Creek, and Cove Creek, support only a few families or a single ranch each. In some places, as at Holden, the water from several streams is led to one settlement, or farmers live in settlements at some distance from their fields and water supply.

Next in agricultural importance to the settlements just described are the communities and ranches that depend on water from Sevier River, including Leamington, the McIntyre ranch at the station of Mack, Burtner, Oasis, Deseret, Hinkley, Abraham, and the Swan Lake farm. Next to these in importance are the communities and ranches in Snake Valley, including Burbank, Garrison, a series of ranches between Garrison and Trout Creek, two ranches at Trout Creek, and three ranches at Callao.

The rest of the region, comprising by far the largest area, is so nearly destitute of water supplies that it contains only a few widely scattered ranches, most of which depend, in whole or in part, upon live stock raised on the range. Ranches of this kind are McIntyre's ranch in Tintic Valley; Rockwell's ranch, on Cherry Creek; Laird's ranch, at Joy; Thomas's ranch, at Fish Springs; James's ranch, at Black Rock; the Clear Lake farm, at Clear Lake station; Ward's ranch, at Rush Lake; and Duncan's ranch, McConnell's ranch, and the Church ranch, in or near the Iron Mountains.

Agricultural establishments of another type that should be mentioned, although they include few permanent settlers, are the large dry farms such as the Utah Arid farm in Dog Valley, and the Juab Development Co. farm in Little Valley.

Approximately one-fourth of the inhabitants of the region are found in mining camps and are dependent in some way on the mining industry. The great majority of these are in the Tintic mining

district, but there are small camps at Fish Springs and Joy, in Juab County, and at Stateline, in Iron County, and prospectors are scattered through the region. Ore deposits are of course located without reference to the present occurrence of water, and the problem of providing a water supply for mines and mining communities may be difficult, as it proved to be in the Tintic district. The mining industry has an important influence on agriculture by creating a demand for agricultural products.

The main line of the San Pedro, Los Angeles & Salt Lake Railroad passes diagonally through this region. Along its entire course, however, it is at some distance from the villages on the east side, its route having been determined by the location of mines and by engineering considerations. A branch line passes through Juab Valley, but the villages in the eastern parts of Millard and Iron counties are remote from any railroad connections. This position of the railroad has brought a certain amount of human life and activity into a desolate desert tract. Oasis, Clear Lake, Black Rock, Lund, and Modena have only a few inhabitants, but they are the supply points for nearly the entire region except eastern Juab County. Incidentally, this position of the railroad required a water supply in the desert tracts and resulted in valuable underground explorations.

The uninhabited condition of a large portion of these counties can best be shown by an example. In that part of Millard County which lies between Black Rock and the Sevier Desert settlements on the east and Snake Valley on the west the only inhabitants are two men, who are at Ibex a part of the time. Yet this is a region of diversified topography, 50 miles wide and 65 miles long, comprising about one-half of Millard County, and is as large as Rhode Island and Delaware combined. Its only product of economic value is a scanty growth of forage plants, which are picked up by flocks of sheep brought thither in the winter season.

The physical conditions and natural resources of the region are distributed in a way that has resulted in producing three types of communities whose people have important differences in character and mode of life; these are the irrigation settlements, the isolated ranches, and the mining towns. The irrigation settlements were founded long ago by the Mormons, and the inhabitants have been powerfully influenced by geographic conditions. Their sociability and hospitality, their simple habits and elemental morals, and their spirit of contentment and general lack of commercial enterprise have no doubt been in large part engendered by the physical conditions that threw them into small, compact, isolated communities, having a comparatively secure livelihood but rigid limitations to industrial expansion.

OCCURRENCE OF GROUND WATER.

BEDROCK.

WATER IN SEDIMENTARY ROCKS.

The indurated rocks comprise limestone, quartzite, conglomerate, sandstone, and shale. The quartzite and hard gray limestone of Paleozoic age are widely distributed, but the conglomerates, sandstones, and shales of younger systems are found mainly along the east margin—in the mountains east of Juab Valley, in the Valley Range and the ridges on both sides of Chicken Creek, in the Canyon and Pavant ranges, in the high plateaus east of Parowan and Rush Lake valleys, in the low range west of Parowan Valley, in the Iron Mountains, and in the highlands farther southwest.

The body of the Paleozoic quartzite and limestone is compact and impervious, but small quantities of water penetrate these rocks through joints and fracture zones; the sandstones and conglomerates, where not too firmly cemented, carry water in the pore spaces; the shale beds contain little water.

If the indurated sedimentary rocks had a favorable topographic attitude they would no doubt furnish moderate supplies of water in many localities, but their attitude is almost everywhere unfavorable for recovering water by sinking wells into them. On the uplands the water that seeps into these rocks is likely to be returned to the surface where the strata outcrop or to penetrate to great depths; on the lowlands the bed rock is buried beneath such thick accumulations of unconsolidated sediments that it can in most places be reached only by very deep drilling. As a result of these conditions little water is obtained from the indurated sedimentary rocks except such as issues in mountain springs, and but few attempts have been made to procure supplies by drilling into these formations.

In the Tintic mining district, in the East Tintic Mountains, a number of shafts have been sunk through Paleozoic limestone to depths of 1,500 to 2,260 feet, or several hundred feet below the water level in the unconsolidated sediments of the adjacent Tintic Valley, without finding any water, and one or two deep mines have encountered small amounts of water at levels considerably below the water level in the valley.

In the Utah mine, which is situated near the north end of the Fish Springs Range and is developed mainly in Paleozoic limestone, no water was found until the workings reached the 800-foot level, which is lower than the Fish Springs and the ground-water table of the plain bordering the mountains. Even at this depth the supply is very small.

In the valley north of Fillmore there is a low ridge consisting in part of quartzite and in part of deep red and blue shale and sand-

stone—the same formations as are found in the Pavant Range. It is nearly buried beneath unconsolidated sediments and forms one of the exceptional localities of this region in which the indurated sedimentary rocks are near the surface and yet not far above the general ground-water level. Here several wells have been sunk, the first to test for artesian water and the rest in search of oil. It appears that the rocks were found to contain considerable quantities of water which is of satisfactory quality and rises within a short distance of the surface. But even here the rocks apparently do not afford more favorable conditions than the unconsolidated sediments, and drilling in them is more expensive.

Near the southern boundary of Iron County, in the vicinity of Enterprise, a test well, drilled to a depth of about 700 feet, is reported to have entered 400 feet of red rock. The rock here also contains water, but according to report it was less in quantity and lower in head than the water in the overlying beds of sand and gravel.

In the southern part of Juab Valley, near the west ridge, which here consists of eastward dipping conglomerates, sandstones, and other rocks of probable early Tertiary age, a well was drilled to a depth of 620 feet, chiefly in rock. The first satisfactory supply found in this well was near the bottom, from which level the water rose to within 22 feet of the surface.

WATER IN IGNEOUS ROCKS.

The igneous rocks include ancient granite, Tertiary intrusives and extrusives, largely of acidic or intermediate composition, and more recent volcanic material, chiefly basalt. The ancient granite lies at the surface in only a few mountainous districts, but it has been reached in deep drilling in Lower Beaver Valley and it no doubt exists far below the surface in other localities. Igneous rocks of Tertiary or more recent age occur in large quantities in the East Tintic Mountains, the Thomas Range, the buttes and mesas of Sevier Desert and of the southeastern part of Millard County, the mountains of eastern Beaver and Iron counties, the low ranges of western Iron County, and in other localities.

The railroad wells at Goss and Neels are reported to have penetrated granite at depths of 1,643 feet and 1,950 feet, respectively, and the Goss well is said to have found great quantities of salty water in crevices of this rock. It is, however, not probable that the granite would generally yield water even where it is within reach of the drill.

The Tertiary igneous rocks are for the most part compact and impervious, but the mining developments in the Tintic district have shown that, at least in that locality, they are ramified by fracture zones which permit a slow seepage to depths of hundreds of feet but

which are not open enough to allow the water to escape quickly, as in fractures in the limestone of the same district. The mines in the igneous rocks, none of which exceed a few hundred feet in depth, contain water, but those in limestone are dry or do not find water until they reach great depths. Moreover, mines that pass through igneous rocks into underlying limestone seem to lose their water when they enter the limestone.

Near the surface the igneous rock disintegrates to form coarse-grained porous débris into which the water that falls as rain can penetrate. Since this débris rests on undecomposed igneous rock that is nearly or quite impervious, the water is prevented from escaping downward, and where the topography is such that it can not readily drain away, it may accumulate and give rise to springs or seeps or afford a supply for shallow wells.

The quantity of water that can be obtained from the disintegrated mantle of the igneous rock or from the fracture zones that penetrate this rock to greater depths is invariably small, but it is nevertheless of great value in localities where no other water is available. In many places supplies from such a source can be increased by increasing the infiltering surface, either by digging more wells of large diameter or by constructing tunnels or infiltration galleries below the water level. Little or nothing can be accomplished by deep drilling.

The most extensive developments of this kind have been made in the Tintic district, where the public supply for the city of Eureka, the supply for one of the railroads, and the supplies for a number of mines are obtained from pumping plants which draw from the partly disintegrated igneous rock and the overlying rock waste. Supplies of this character have also been developed at Joy and elsewhere.

A number of springs of fair size exist in those parts of the East Tintic Mountains in which the surface formation consists of igneous rock (Pl. V), and the water from some of them is conducted through pipe lines to Silver City, Jericho, and the Utah Arid farm. Small springs of similar character found in the low mountains of western Iron County, where igneous rock underlies the surface débris, provide valuable watering places for live stock on the range.

The more recent basaltic lavas are in many places broken by joints and fissures, through which water can pass freely and through which it may escape at low levels in large springs. Examples of groups of springs that appear to be of this type are the Black Rock Springs, the Clear Lake Springs, the Hot Springs north of Abraham, and the springs at Rush Lake, each of which yields at least a second-foot of water. The well at Ward's ranch (near Rush Lake) also derives its water from a crevice in lava rock.

CONFINING FUNCTION OF BEDROCK.

For the region as a whole, the indurated rocks, both sedimentary and igneous, are not of much importance as water-bearing formations. Their chief value lies in their confining function in the basins which they form and which are partly filled with unconsolidated water-bearing sediments. The small perched basins may allow of so much leakage that their unconsolidated sediments are entirely drained, but the large basins, which are relatively depressed, although high above the level of the sea, are sufficiently waterproof to cause the accumulation of water in the unconsolidated sediments. In this way the rock basins act as huge reservoirs whose supplies of water can easily be drawn upon in the lowland areas, and are, therefore, of great economic value. As the Tertiary igneous rocks are as a rule less permeable than the Paleozoic limestones, the basins underlain by them are more likely to contain water than those underlain by the limestones.

UNCONSOLIDATED SEDIMENTS.

CHARACTER OF SEDIMENTS.

The sediments that partly fill the rock basins, thereby forming "valleys" and "deserts," are derived from the mountainous rims of these basins, where the firm rock is subjected to the destructive activities of the weather. Ever since the great deformations which brought the basins into existence the rocks in the uplands have been disintegrating at the surface and the resulting rock waste has been swept away, chiefly by torrential storm waters, and deposited in the low parts of the basins. Hence the serrate peaks and deep canyons and myriad of gullies with which the uplands are sculptured. Hence also the extensive smooth alluvial slopes and desert plains underlain by thick deposits of clay, sand, and gravel.

The stream, lake, and wind deposits which fill the basins are here grouped under the collective name of "unconsolidated sediments" in order to differentiate them from the hard igneous rocks and the ancient indurated sedimentary formations which are together called "bedrock." It should, however, be understood that some of the stream, lake, and wind deposits have become firmly cemented, and that a certain amount of cementation has generally taken place, as is shown by the fact that dug wells are usually not cased above the water level.

The unconsolidated sediments are by far the most valuable water-bearing beds of this region. Nevertheless, they are not good water producers in every locality nor at each horizon, the principal difficulties being (1) that they may be drained of their water, (2) that they may consist entirely of fine-grained materials which will not

surrender water freely, and (3) that they may contain only salty water.

WATER IN STREAM DEPOSITS.

When a stream escapes from its canyon and its carrying power diminishes it drops the coarsest part of its load first and conveys the finest sediments farthest into the valley or desert. Hence the upper parts of the alluvial slopes consist largely of gravel and bowlders, and the parts most remote from the mouths of the canyons are underlain by beds of clay and fine sand associated with little gravel and no bowlders.

A swollen stream sweeping rapidly down a steep, narrow canyon can move great quantities of gravel and roll along large bowlders, and even on the alluvial slope it is able to carry the coarse parts of its load much farther than when it has only its normal size, bowlders being transported at times of flood to almost incredible distances from the mountains. Hence coarse sediments come to be superimposed on fine sediments, and, in sinking a well, successive beds of clay, sand, gravel, and even bowlders will be encountered.

Since the aggrading streams flowing over the alluvial slopes change their courses frequently, depositing débris now in one locality and now in another, the beds underlying these slopes are not continuous, and wells only a short distance apart may show entirely different sections.

In most localities the stream deposits include beds of sand and gravel that are capable of yielding water freely. As the distance from the mountains increases, the number and thickness of these beds decrease, their constituent particles become smaller, and their yield of water becomes correspondingly less copious; but fairly abundant supplies can generally be obtained even in the valley flats. The principal difficulty in connection with the stream deposits is that in the upper parts of the alluvial slopes the porous beds are drained to great depths, in some places even to the bedrock.

WATER IN LAKE DEPOSITS.

Since the conditions of sedimentation are much more uniform at the bottom of a lake than on an alluvial slope, the lake beds are more continuous and regular than the stream deposits, and wells in the same vicinity have nearly the same sections. In the quiet waters of a lake the gravel and sand brought by streams sink near the shore and only very small particles that stay long in suspension reach points remote from the shore. Hence lake deposits are likely to consist so largely of beds of clay and fine-grained quicksand that they will yield only meager supplies of water. Especially is this condition imminent near the center of extensive lake beds such as

Great Salt Lake Desert and Sevier Desert. Salt is likely to be deposited in lakes that have no outlet, and the ground water found in the lake sediments may therefore be saline. Both of these unfavorable conditions are encountered in this region.

WATER IN LOW VALLEYS.

A typical valley of this region consists of a rock trough partly filled with sediments so disposed as to form alluvial slopes on each side with a central flat between. Stream deposits underlie the alluvial slopes but lake deposits may occur at the center. In many valleys the sediments are saturated to the level of the central flat. As new supplies of water are poured out from the mountains and absorbed by the porous gravel of the alluvial slopes the amount of ground water is increased and some of it returns to the surface in the lowest parts of the central flat, either in springs or by imperceptible capillary action, and is removed by evaporation, or, less commonly, flows out of the valley through a drainage outlet. (See fig. 5.) On the central flat and the lower parts of the alluvial slopes the ground water is therefore near the surface and can easily be obtained by sinking wells into the unconsolidated sediments.

The most favorable location for wells is at the base of an alluvial slope where the surface is not far above the ground-water level but where coarse water-bearing beds are still plentiful, on the side of the valley bordered by the mountains which furnish the most water, and in the vicinity of the largest streams. The wells in the flats generally yield less freely.

Juab Valley, Parowan Valley, and Rush Lake Valley are typical of the kind of valleys just described. Their sediments are saturated to a level controlled by their central flats, and the best wells are obtained near the base of the east slopes, which receive the principal water supplies. Pavant Valley (Holden to Kanosh), Little Valley, Tintic Valley, and Snake Valley are also of this type, though somewhat modified. Each has one or more low tracts along the central axis, where the ground water is returned to the surface, showing the saturated condition of the sediments below the level of these tracts.

WATER ON DESERT FLATS.

The deserts, like the valleys, are surrounded by alluvial slopes which descend from the upland borders, but they differ from the valleys in having more extensive central flats with a more important development of lake deposits. At the base of the alluvial slopes the conditions are not unlike those found in the valleys, as is illustrated by the wells at Callao, in western Juab County, and those in the vicinity of Enterprise and New Castle, in Iron County. The desert flats, like the valley flats, lie so low that the ground-water level

is near the surface, but they differ from the valley flats in being underlain more largely by non-water-bearing clay and quicksand and by beds that make the water salty.

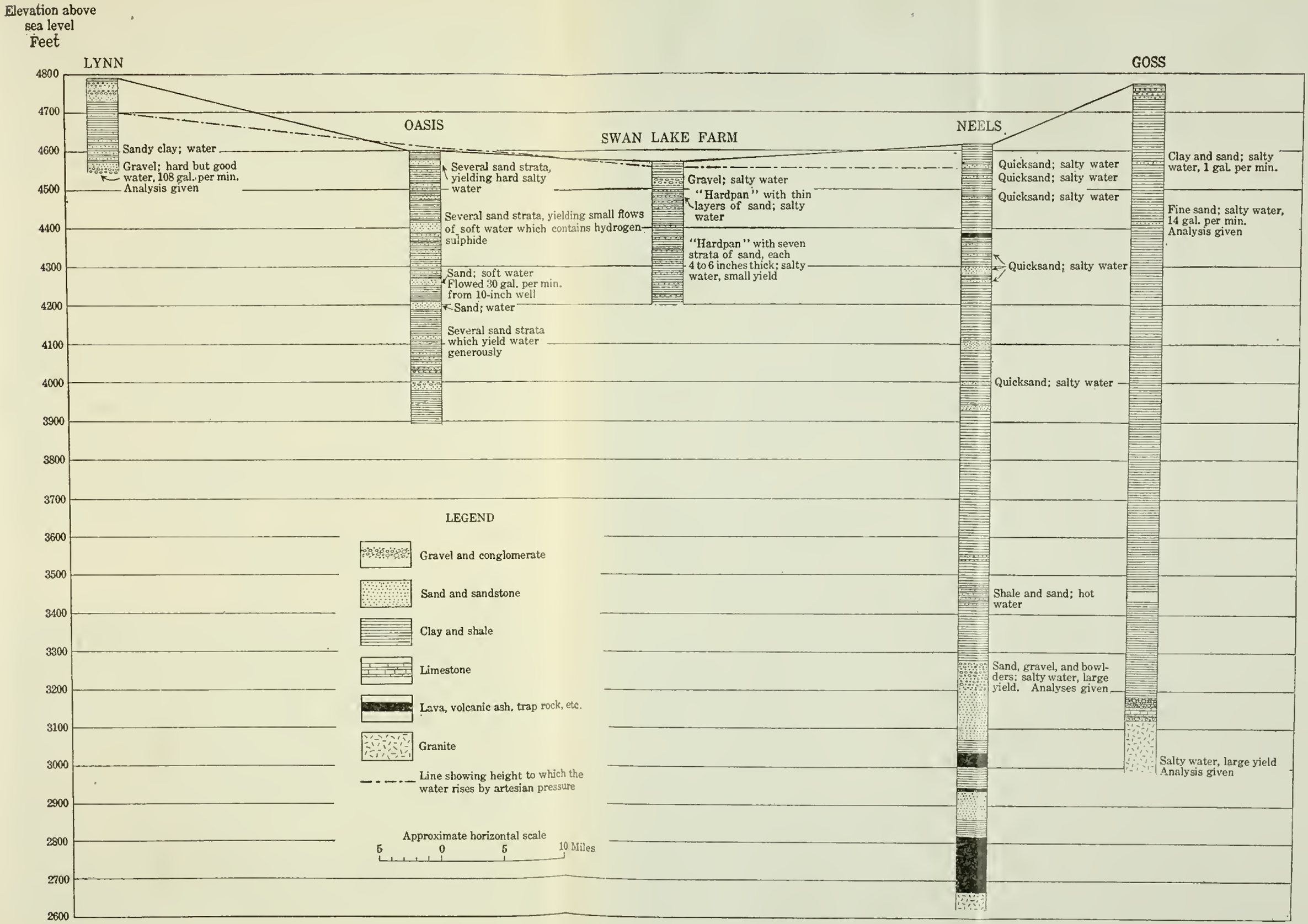
Sevier Desert includes the Lynn bench and the adjacent low flat (Pl. I). The Lynn bench is a relatively level upland tract formed essentially as the delta of Sevier River in the Provo stage of Lake Bonneville. It consists largely of sandy and gravelly material which absorbs much of the rainfall. At Lynn a successful well was drilled by the railroad company, and good wells could probably be obtained on most parts of the bench. As at Lynn, however, the water level is probably everywhere at some distance below the surface.

At Deseret and the other settlements on the flat near the base of this bench many successful wells have been drilled. Here the sediments consist chiefly of clay and include very little gravel, but there are numerous beds of sand, all of which are charged with water that rises nearly to the surface or a little above the surface. The principal source of supply is evidently the Lynn bench.

Farther southwest, at greater distances from the bench, conditions rapidly become more unfavorable for ground-water supplies. The proportion of clay becomes greater, the sand becomes finer, and the water becomes meager in quantity and so salty that it is generally not fit to use. At Goss station, remote from the Lynn bench, the railroad company drilled through hundreds of feet of dense clay or shale that is almost totally destitute of water.

In brief, the sediments underlying Sevier Desert were supplied chiefly by Sevier River, and consequently they become finer as the distance increases from the mouth of the canyon at Leamington, where the river began to deposit its load. This condition is shown in Plate III. Neels and Goss are situated near the Cricket Mountains (Beaver Range), and it might have been expected that gravel from this range would be intercalated between beds of clay derived from more distant sources, but, according to the well sections, such local materials are almost entirely wanting.

Great Salt Lake Desert extends into the northern part of Juab County, forming the Fish Springs Flat and the flat between the Deep Creek Range and the Fish Springs Range. In the vicinity of Callao, at the base of the large alluvial slope of the Deep Creek Range, a number of good wells have been obtained, but in several holes sunk on the flat near the Fish Springs Range only salty water was found. The western part of this flat may have received some contributions of coarse sand from the streams that drain the Deep Creek Range or from water which in more humid periods probably issued from Snake Valley, but the eastern part of this flat and the entire Fish Springs Flat had no important source of local sediments. At its north end the Fish Springs Range is almost devoid of an



WELL SECTIONS IN SEVIER DESERT AND LOWER BEAVER VALLEY.

the House and Confusion ranges. (See Pl. IV.) On these large slopes all the sediments above the rock formations are likely to be dry, and the prospects of obtaining water at any practicable depth are very poor.

In some places where layers of clay alternate with beds of sand and gravel the water is prevented from sinking below the clay layer but percolates along its upper surface. Where such a condition exists small supplies are found unexpectedly near the surface, as, for example, in the wells at Holden. (See fig. 12, p. 92.)

WATER IN HIGH VALLEYS.

The absence of springs and alkali flats in the lowest part of a valley should be regarded as an unfavorable indication. It shows that the unconsolidated sediments are not saturated to the level of the lowest part of the valley, and it leaves no clue as to whether these sediments contain any ground water or are entirely dry. If the basin is inclosed on all sides and is underlain and bordered by impervious formations, such as the Tertiary igneous rocks, it may contain some water, but if it is only partly inclosed or is underlain by fissured rock, such as the Paleozoic limestones, its water is likely to be drained to lower levels.

The principal regions containing elevated valleys that have no surface indications of ground water are the high country between Juab Valley and Tintic Valley and the mountainous district between Sevier Lake and Snake Valley.

ARTESIAN CONDITIONS.

BEDROCK.

The conditions in Juab, Millard, and Iron counties are unfavorable for obtaining flowing wells from rock formations. In most places the strata in the mountains dip away from the adjacent valleys or are so much contorted and broken that they preclude all possibility of giving rise to artesian pressures. In some places they dip toward the valleys, but at so great an angle that they are carried to profound depths before they reach the lowlands where they might furnish artesian water. Moreover, the rocks which might bear water are not generally covered by competent confining beds, or the latter are so greatly faulted and fractured that they are ill adapted for holding water under pressure.

Within this region there is no flowing well that is known to derive its water from bed rock and no locality where the prospects for obtaining flows from rock formations are sufficiently good to warrant the expensive drilling that is necessary to make a test. There is a common fallacy to the effect that where flows are obtained from

the unconsolidated sediments much stronger ones could be secured by drilling deep into the bed rock. In fact, however, artesian conditions in the unconsolidated valley deposits bear no relation to conditions in the deeper lying bed rock, and are not in any sense an indication that flows could be secured by drilling into the deeper solid formations.

UNCONSOLIDATED SEDIMENTS.

FLOWS IN THE VALLEYS.

In order to understand the artesian conditions in the unconsolidated sediments it is necessary to recall some of the relations that have already been explained. In many of the valleys these sediments are saturated to the level of the low central flats. (See fig. 5.) New supplies of water are poured into these valleys and sink into the

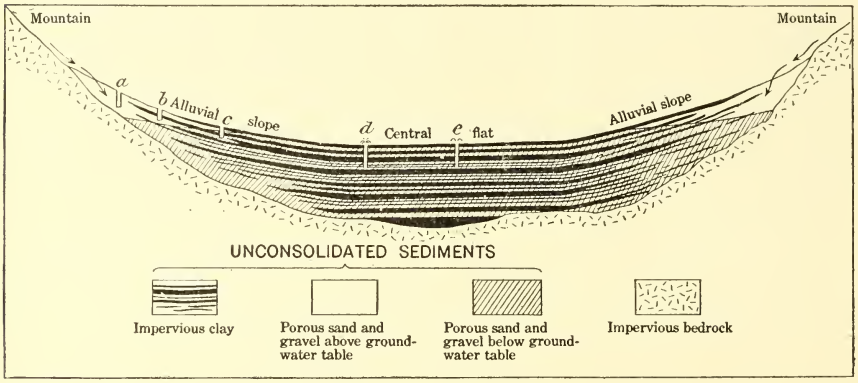


FIGURE 5.—Diagrammatic cross section of a typical valley, showing ground-water conditions: (*a*) Dry hole which if sunk deeper would strike bed rock without finding water. (*b*) Dry hole which would find water if sunk deeper. (*c*) Pump well of moderate depth. (*d*) Strong flowing well. (*e*) Weak flowing well.

gravelly upper parts of the alluvial slopes. Thus the water beneath the slopes accumulates till it stands above the level of the central flats, and consequently moves slowly toward these low flats, where it reappears at the surface and is generally disposed of by evaporation, leaving behind the salts that it had taken into solution in the ground, in this way forming the alkali crusts found in low places.

The unconsolidated sediments consist of gravel, sand, and clay. Beneath the higher parts of the slopes gravel predominates, but farther down in the valley it gives way largely to alternating beds of sand and clay. These beds are nearly level where they lie beneath the central flat, but curve upward where they extend beneath the bordering slopes. (See fig. 5.) The gravel and sand are porous and therefore allow water to percolate through them rather readily, but the clay is so dense that it is relatively impervious to water. The water which sinks into the gravel in the higher parts of the slopes

and travels toward the central flat becomes confined below layers of clay, and the water which accumulates back of it places it under pressure. This pressure may become so great that when the clay layers are punctured, as in drilling, the confined water will escape to the surface, forming flowing wells. (See fig. 5.)

If the clay layers were perfectly impervious the head of water would in many valleys be great enough to produce flows with strong pressure, but in fact they allow the water to penetrate them to such an extent that flowing wells seldom have a head of more than a few feet. For this reason springs, seeps, and alkali flats, by showing that the ground water is under sufficient pressure to escape to the surface, are indicators of artesian conditions. A valley showing no overflow in the low places has poor prospects for flowing wells.

Large, steep alluvial slopes and an abundant water supply from the mountains are also promising conditions for flows. Stronger wells are generally obtained near the base of a slope than farther out on the flat because the slight disadvantage in level is more than counterbalanced by the greater coarseness of the sand and gravel and the closer proximity to the supply.

It is evident from figure 5 that only a small part of the water now stored in the ground would flow out of wells without pumping. It is also evident that the amount of water that can be recovered from flowing wells each year, though dependent upon the annual increment, is probably indicated pretty closely by the amount that annually escapes to the surface in low places. This is far from being the unlimited quantity that is so frequently postulated for artesian basins. Yet it must be remembered that the water that issues in the visible form of springs is probably only a small part of the total amount that escapes. Larger quantities generally come to the surface through capillary pores and evaporate unnoticed or with no other indication of their escape than the alkali that they leave behind.

Flowing wells of the type described are in the north and south basins of Juab Valley, in the north and south basins of Rush Lake Valley, and in Little, Tintic, and Parowan valleys (Pls. I and II). The greatest number are in Parowan Valley and in the north basin of Juab Valley. Nearly all the wells are of small diameter and most of them furnish but little water. Some of the strongest flows are in Parowan Valley, where a few 3-inch wells yield more than 40 gallons per minute each and the total yield in the irrigation season amounts to several second-feet.

More water could probably be recovered from flowing wells in all of the valleys mentioned. Parowan Valley has been developed most extensively; Juab Valley perhaps presents the best opportunities of further development, and Rush Lake Valley also offers a field for further explorations. Pavant Valley (Holden to Kanosh) has been

rather thoroughly prospected and the results have been disappointing. In the low parts of this valley the water rises nearly to the surface, but nowhere have flowing wells of any consequence been obtained. The large alluvial slopes and abundant water supply on the east side appear promising, but the interrupted lava beds on the west side may introduce an unfavorable structure. The drilling done in Snake Valley above Trout Creek likewise failed to obtain flows, although in several wells the water rose nearly to the surface. However, this valley has not yet been thoroughly prospected. There is also a chance for flowing wells in Round Valley, where some prospecting has been done, and they might possibly be obtained in certain restricted localities in the drier valleys of the region.

Wells intended to supply water for irrigation should be made larger and should be sunk deeper into the unconsolidated sediments, where they may discover strong water beds that are not now tapped. The casing should be perforated to admit water at all levels where satisfactory water-bearing beds are found. Many believe that very deep expensive drilling would reach water under phenomenal pressure sufficient to cause it to flow even on the bench lands, but this belief is without foundation and affords no justification for expending public or private funds in attempting to get flowing wells on the upper parts of the alluvial slopes.

FLOWS IN THE DESERTS.

Over large tracts of the extensive ancient lake bottoms that now form desert flats, such as Great Salt Lake Desert, Sevier Desert, and Escalante Desert, the ground is saturated practically to the surface, and ground water is slowly evaporating. Here wells obtain water under sufficient pressure to rise within a few feet of the surface, or, in certain localities, to flow above the surface. In principle these wells do not differ greatly from the wells in the valleys. Their supply comes from the surrounding alluvial slopes and is imprisoned in beds of sand beneath layers of clay. The areas in which flowing water may be expected as a rule lie close to the base of the large slopes or benches which furnish abundant supplies of water and do not extend to the interior of the deserts, where the surface is slightly lower. However, in the interior areas the sediments are so completely saturated and the water from different horizons comes so near the general desert level that a slight depression in the surface may be sufficient to make weak flows possible.

Flowing wells of this type are found in Sevier Desert, at the margin of Great Salt Lake Desert, and in Escalante Desert. The flowing wells on the Beaver Bottoms, south of Black Rock, nearly all of which lie in Beaver County, can also be included in this class.

In Sevier Desert flowing waters are found in at least two distinct areas—the Deseret area and the Desert Wells area. The Deseret area which is the largest and most important area of flow in the region under consideration, contains several hundred wells whose water either overflows or rises so near the surface that no pumps are required. The second contains only a small group of flowing wells, several miles north of Sevier River, and has not yet been thoroughly explored. Both areas lie near the base of the Lynn bench, from which they are evidently supplied. Promising localities for further exploration are along the foot of the bench east of Oasis and north of the Desert Wells. The extensive sandy upland that reaches from Sevier River nearly to Cherry Creek can hardly fail to provide a copious supply of ground water to the lowland that borders it on the west.

The only flowing wells in that part of Great Salt Lake Desert which extends into this region are in the vicinity of Callao. They are situated at the margin of the desert and derive their waters from the large alluvial slope of the Deep Creek Range immediately to the west. Flows can probably not be obtained more than a few miles east of Callao although the surface descends slightly in that direction.

Two flows have been struck in Escalante Desert—one near the west margin and the other in a low tract in the interior. Flows with slight pressure can probably be obtained in other parts of this desert.

In the desert areas, as in the valleys, stronger flows could be obtained by drilling wells of larger diameter to greater depths and by admitting water at more than one level, but no great increase in head is to be expected from deep drilling.

SPRINGS.

MOUNTAIN SPRINGS.

The springs of this region fall into two general classes: Mountain springs and valley springs. The mountain springs include seepage springs and structural springs.

Rain or snow falling on the mountain areas may sink into the disintegrated material that in some localities covers the firm rock and may percolate through this loose surficial material until it reaches a place where it is forced back to the surface by an outcropping ledge of rock. These springs, which may be designated mountain seepage springs, are sensitive to differences in rainfall, and vary greatly in their discharge, as is illustrated by Plate V, in which the flow of a spring of this kind is plotted with the rainfall during the same period.

In the arid basin ranges the principal formations are Paleozoic limestones and quartzites and Tertiary igneous rocks. As the igneous

rocks have fewer fissures and crevices through which the water may escape, and are covered with more rock waste than the limestones and quartzites, most of the seepage springs are found in the areas of igneous rock, as is well illustrated in figure 10 (p. 83).

The water that falls on the mountain areas may not merely sink into the surficial rock waste, but may penetrate the joints, fissures, bedding planes, solution cavities, or pore spaces of the bedrock and descend far beneath the surface. As the relief of the mountain areas is great and the rocks are much deformed, some of these passages lead to the surface at lower levels, where the water that entered them higher up in the mountains gushes forth in the form of springs. This type, which may be designated structural springs, is most common in the sedimentary formations of the mountains that have abundant precipitation. The discharge of such springs is more nearly uniform than that of seepage springs and constitutes an important part of the low-water flow of the permanent streams of this region. A striking example of this class is the Warm Spring at Gandy, in Snake Valley, where a great volume of warm water issues from the face of a limestone cliff.

SEEPAGE FROM UNCONSOLIDATED SEDIMENTS.

It has been fully explained (pp. 34–36) that in most of the large rock basins, known as "valleys" and "deserts," the filling of unconsolidated sediments is saturated with water to the level of the lowest parts, and that as new supplies are added overflow occurs in these low places. Though much of this overflow is accomplished through minute pores in the soil from which the water is evaporated so promptly that the process is quite unnoticed, some of it is accomplished by a definite flow of water out of larger openings in the ground, forming springs or seeps. Springs of this character do not give a measure of the amount of overflow of the underground reservoirs, but they are important in showing that such overflow is taking place. Like the flowing wells, to which they are closely related in origin, they occur most generally at the base of the alluvial slopes that have copious water supplies and are less common in the interior portions of the flats.

Seepage springs are also likely to occur where the unconsolidated sediments have been eroded, as along stream channels and ancient shore lines. In some such places water is percolating along the upper surface of an impervious layer high above the normal ground-water level, and if the stream or wave erosion has extended down to this layer a line of springs results.

SPRINGS FROM LAVA BEDS.

It has already been pointed out (p. 31) that the basaltic lavas, which are the youngest igneous rocks of the region, contain joint planes and other openings along which water can percolate with relative freedom; and that where these rocks lie at low altitudes they may give rise to large springs. Black Rock Springs, Clear Lake Springs, the Hot Springs north of Abraham, and some of the springs between Enoch and Rush Lake have been cited as examples of large springs of this type.

HOT SPRINGS.

Near the surface the temperature of the ground fluctuates with the seasonal changes in the weather, but at a certain depth below the surface the earth and the water which it contains are not affected by these changes but maintain constant temperature, which is approximately the mean annual temperature of the region. The mean annual temperature was found to be 47° F. at Levan (for the period between 1890 and 1903, inclusive) and 51° at Fillmore (for the period between 1892 and 1903, inclusive).[1] At greater depths the rock and the water which it contains become gradually warmer, the increase generally being 1° F. for about 50 to 100 feet of increase in depth. But where hot lava has been brought to the surface or intruded into the older formations the downward increase in temperature is much more rapid, even though the volcanic activity may have occurred many thousands of years ago. Moreover, where the rocks have been deformed heat has been produced by the friction involved, and here the downward increase in temperature may also be rapid. If the temperature of the water that comes from a spring is higher than the mean annual temperature of the region, the spring is, strictly speaking, a thermal spring. The high temperature indicates that the water comes from a deep source or from rocks that have been heated by volcanic activity, by deformative movements, or possibly by some other agency.

This region contains a number of springs whose water is distinctly warmer than normal. The principal ones are the Hot Springs north of Abraham, the Hot Springs, northeast of Fish Springs Range, the Warm Spring near Hatton, the Warm Spring at Gandy, the Big Spring south of Burbank, some of the Fish Springs, and some of the pool and knoll springs of Snake Valley. The Hot Springs north of Abraham and the Warm Spring near Hatton are in close relation to volcanic formations and their water evidently derives its high

[1] Henry, A. J., Climatology of the United States: U. S. Dept. Agr., Weather Bureau Bull. Q, 1906, pp. 833, 834.

temperature from them; the others seem to be related to faults in the rocks and their water is probably warm because it comes from great depths or from rocks that have been heated by deformation.

POOL AND KNOLL SPRINGS.

Pool and knoll springs include an important class of peculiar springs, typical examples of which are found only in Snake and Fish Springs Valleys, though springs having some of their characteristics are found in other parts of the region. In this class belong the Fish Springs, Devil's Hole, Knoll Springs, Kell Springs, Bishop's Springs (at Foote's ranch), some of the springs between Foote's ranch and Trout Creek, Willow Springs, Redding Springs (in Tooele County), and perhaps the Hot Springs northeast of the Fish Springs Range. The location of most of these springs is shown in Plate IV, and all except Redding Springs are described in the sections of this paper dealing with Fish Springs Valley and Snake Valley (pp. 124–126 and 129–133). Many of them yield warm water, and have already been mentioned in the discussion of hot springs.

They are of two types, which differ completely in their external appearance but occur in close proximity to each other and are evidently related in origin. The pool springs are large deep reservoirs filled with clear water, and many of them are inhabited by small fish. At the top the reservoir or pool is bordered by a shelf that extends over the water surface, giving the pool somewhat the shape of a jug or cistern. The shelf appears to be composed largely of a felt-work of vegetable fibers and to be formed by the joint work of plants and wind. The plants at the margin extend inward across the face of the water producing a tangle in which the wind deposits sand and dust. In this manner a soil is formed on which the plants can develop further and close in still more on the water area. Chemical precipitates from the water form no important part of these shelves.

The knoll springs consist of mounds or knolls, in few places more than 10 feet high, from the top or sides of which water flows. The knolls appear to be a development of the shelves of the pool springs. They yield less water than the pool springs in the same locality, evidently because the water is under less head. Thus there appears to be a limit to the growth of the knolls, and their construction involves the decline of the springs that have given them origin.

That these springs are not merely the return to the surface of water that percolates into the sediments of the adjacent alluvial slopes seems to be shown by the following facts: First, the yield of many of them is larger than would be expected if they were supplied from local sources; second, their yield is nearly uniform,

though that of ordinary valley springs fluctuates with the season; third, their location differs from that of ordinary valley springs, the Hot Springs and the Fish Springs, with their copious flow, being near the end of a narrow and dry range, with almost no alluvial slope, and some of the largest springs of Snake Valley, such as those at Foote's ranch, being on the east side of the valley, where relatively little water is supplied by the low, dry Confusion Range; fourth, the temperature of many of them is distinctly higher than the mean annual temperature of the region, which is not the case with springs fed from shallow and local sources. All these differences suggest a relation to the rock structure, and such a relation is further suggested by the somewhat linear arrangement of the different groups and by the evidences of recent faulting recorded by Mr. Gilbert near Hot Springs, Fish Springs, Willow Springs, Redding Springs, and Knoll Springs. As the tendency of the pools to become inclosed by a shelf or knoll seems to depend on the encircling vegetation, and as the luxuriance of this vegetation may result from the warmth of the water, it may be that the knolls are in this way genetically related to the rock structure.

QUALITY OF GROUND WATER.

SUBSTANCES CONTAINED IN WATER AND THEIR EFFECTS UPON ITS USE.

The water that falls as rain or snow contains little or no mineral matter, but when it enters the ground and percolates through the earth it gradually takes into solution substances with which it comes into contact. Therefore underground water always contains some dissolved mineral matter. As long as this matter is in solution it is invisible, but when the water evaporates, as in a teakettle or a steam boiler or on the surface of a low valley flat, the mineral matter is left behind and forms a crust or scale. Ground waters differ greatly in the total amount of substances contained in solution and also in the proportions of the different substances. The most common of these substances are calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulphates, and chlorine. When, by the evaporation of the water or some other process, these substances are thrown out of solution, they form compounds such as calcium carbonate (limestone), calcium sulphate (gypsum), sodium carbonate (black alkali), sodium sulphate (Glauber's salt), and sodium chloride (common salt).

Water will also take up organic matter with which it comes into contact, and this organic matter may contain myriads of bacteria that become suspended in the water.

The character of water and its value for various uses depends largely on the substances it contains in solution or suspension.

Small amounts of the common mineral constituents are not harmful to health. Chlorides are not objectionable in drinking water if only 50 to 100 parts per million are present, but amounts clearly perceptible to the taste render water unpalatable. Magnesic and sodic sulphated waters are laxative and very high magnesium or sodium content renders water unfit for man or beast. The worst form of alkali water is that which contains alkali carbonates.

Most of the bacteria that water may contain are probably harmless, but among them may be the germs that produce typhoid fever or other disease. Hence water that is known to contain a large number of bacteria or a large amount of organic matter is regarded with suspicion, and if some of the bacteria are of the kind that come from the intestines of man or other animals the water is considered unsafe for drinking and general household uses.

Calcium and magnesium render water hard and therefore poor for toilet and laundry uses. When water is boiled bicarbonates are decomposed and an equivalent amount of calcium and magnesium is removed, but the calcium and magnesium in excess of this amount, such as would be present in gypsiferous waters, can not be precipitated by boiling. Sodium and potassium do not consume soap and therefore do not make water hard.

Calcium and magnesium compounds are the principal constituents of the scale that forms in boilers. Sodium and potassium compounds do not form scale, but when they occur in large quantities they cause foaming and priming in boilers.

Among the common alkali salts, the least injurious to plants are the sulphates, the most injurious are the carbonates, and the chlorides occupy an intermediate position. Whether water of a certain quality can be successfully used for irrigation usually depends on a number of related conditions, among which may be mentioned the type of crop that is to be raised, the amount of alkali already in the soil, the natural drainage of the land or the ease with which artificial drainage could be established, and the cost and abundance of the water itself. If the land is poorly drained and water containing considerable quantities of alkali is applied sparingly, the evaporation of this water results in the gradual accumulation of alkali in the soil; but if the land is well drained and the same kind of water is applied in large quantities the alkali that would otherwise accumulate in the soil is washed out. T. H. Means[1] states that the limit of concentration for irrigation water has been placed by some authorities at 300 parts per million of sodium chloride (common salt) or sodium carbonate (black alkali) and at from 1,700 to 3,000 parts per million of the less harmful salts; that these limits are probably high enough

[1] The use of alkaline and saline waters for irrigation: U. S. Dept. Agr., Bur. Soils Circular 10.

where water is sparingly used, and that even then all except the most sandy soils or those with exceptionally good natural drainage would ultimately be damaged. But he describes certain gardens in Sahara Desert, in which vegetables considered sensitive to alkali are successfully irrigated with water that contains as much as 8,000 parts per million of soluble salts of which as much as one-half is sodium chloride. In these gardens a very thorough system of drainage was established and the water was applied frequently in large quantities.

WATER FROM THE MOUNTAIN AREAS.

The mountain streams of western Utah are fed partly by springs and partly by the run-off from rain and melting snow. The water of these streams is, in general, moderately hard, but not otherwise highly mineralized, most of the dissolved solids probably being contributed by the springs. It is used chiefly for irrigation and is nearly everywhere good for this purpose.

The water derived from the Tertiary igneous rocks and overlying loose waste likewise generally contains only moderate amounts of dissolved solids, as is shown by the analyses given in the section on the Tintic mining district (p. 85).

GROUND WATER IN THE VALLEYS.

The water in the beds of sand and gravel beneath the alluvial slopes does not differ greatly in its mineral content from that in the mountain streams, though on the average it is probably somewhat harder. In the central flats, where the soil contains considerable alkali, the water near the surface may be charged with sodium salts, but the deeper ground water is ordinarily of good quality. Most of the springs in low places also furnish good water, though some of them have deposited enough mineral matter to produce alkali flats.

GROUND WATER IN THE DESERTS.

On the alluvial slopes bordering the large desert flats and near the base of these slopes the ground water is generally of good quality, being comparable to that in similar situations in the valleys. The flowing wells at Callao serve as an example. But in the interior of the desert areas much of the ground water is saline.

The mineral character of the ground water in the vicinity of Deseret is especially interesting. The water in the upper beds is so salty that it is not used, but the water in the deeper beds thus far encountered by the drill does not contain enough salt to make it objectionable for drinking and household use, though it contains more than is generally found in the water beneath the alluvial slopes. The water from most of the deeper beds contains hydrogen sulphide

gas, which imparts a characteristic odor and tends to come out of solution in small bubbles when the water is brought into contact with the air. This deeper water is softer than most of the water of the region.

Water is made hard by its content of calcium and magnesium, which are derived largely from calcium carbonate and magnesium carbonate. But these carbonates can be dissolved by the water only through the aid of carbon dioxide, and the carbon dioxide is supplied chiefly by decomposition of vegetable matter in the soil. It has been explained that the principal ground-water supply of the region comes from the high mountain areas, which have relatively heavy precipitation and abundant vegetation, but that the supply for the vicinity of Deseret comes in large part from the Lynn bench, which has only a scanty desert vegetation. It is possible that this difference in vegetation, resulting in a difference in the supply of carbon dioxide, may account for the deficiency of calcium and magnesium, and hence for the softness of the water. This hypothesis accords with the analysis given on page 116.

The wells on the flat of Sevier Desert that supply good water are all within a few miles of the margin of the Lynn Bench. Deep wells farther southwest yield highly mineralized water. Every water-bearing bed in the railroad wells at Goss and Neels, which are, respectively, 1,775 and 1,998 feet deep, yields salty water.

Similar conditions exist on the flat between Deep Creek and Fish Springs ranges. The wells at Callao yield good water, but in several wells drilled near Fish Springs Range only salty water has been discovered.

In Escalante Desert more satisfactory water has been found. The drilled wells at Lund and Beryl, Webster's flowing well, a large number of the dug wells, and the deep wells at Milford yield water of fairly good quality, but on the flat between Milford and Black Rock most of the deep wells yield salty water.[1]

WATER FROM SPRINGS.

The character of the water from the mountain springs and the ordinary lowland seepage springs has already been discussed, but the character of the water from several less common types of springs requires special mention.

The Black Rock Springs and most of the other springs from lava beds yield water that is only moderately mineralized, but the water from Clear Lake contains considerable mineral matter, and that of the Hot Springs north of Abraham is very salty.

[1] Lee, W. T., Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 46.

With a few exceptions the pool and knoll springs in Snake and Fish Springs Valleys yield water that is good to the taste. The Hot Springs northeast of the Fish Springs Range and the Warm Spring near Hatton, like the Hot Springs north of Abraham, yield highly mineralized water.

IRRIGATION WITH GROUND WATER.

DEVELOPMENTS.

The total area at present irrigated with water from wells does not exceed a few hundred acres, and nearly all of this water comes from flowing wells. The most extensive developments have been made in Parowan Valley, and Juab Valley ranks second in this respect. Small tracts are irrigated with artesian water at Callao and in some other areas.

Pumping for irrigation has been attempted at the Desert Wells (north of Burtner), on the farm of Edgar Warton (west of Holden), and to a slight extent in Juab Valley and elsewhere. The Desert Wells and Warton projects have been abandoned and no specific data in regard to them were obtained.

At the Desert Wells the water rises to the surface, but pumps were installed, apparently for the purpose of supplying water in larger quantities and of lifting it to a little better land than that on which the wells are located. These wells are so small in diameter and so shallow that they probably did not yield very large quantities of water. Moreover, the soil is heavily charged with alkali (as is shown by the analysis given on p. 110) and the drainage is poor.

The farm of Edgar Warton is situated on the flat between Holden and Pavant Butte (Sugar Loaf Mountain), where the ground water is near the surface. Several wells of large diameter were here dug to a depth of 40 feet. The water was lifted first with windmills and later by means of a gasoline engine.

PROSPECTS.

More land could be irrigated with artesian water if wells of larger diameter, tapping a greater number of water-bearing beds, were sunk, and if such wells were more widely distributed over the favorable districts. As the areas of flow do not extend far beyond the limits of the alkali flats only the outer zones are ordinarily available for agriculture, but in order to recover the largest amounts of water the wells should be widely distributed along these zones. It is also important to conserve the water by allowing it to flow only when it can be used.

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At best, however, the amount of land that can be irrigated with flowing wells is small, the difficulty being that the head is everywhere so low that the yield is not large and trouble with alkali generally threatens where flows of consequence can be obtained. A short distance up the slope from the margin of a flowing area and at a slightly higher altitude the soil is generally better. Here the water in drilled wells will stand near the surface and a moderate pumping lift will suffice to raise comparatively large quantities to a position where it can be used for irrigation.

Irrigation by pumping from wells could probably, by wise management, be made successful in Juab, Round, Pavant, Parowan, Rush Lake, and Snake valleys, in parts of Escalante Desert, and on a smaller scale in other areas, such as Tintic Valley. In Sevier Desert, where trouble with alkali menaces, ground water might be successfully used for irrigation after an efficient system of artificial drainage has been installed. Possibly the water from the large pool springs could also be made available by pumping.

The principal factors that must be considered in pumping for irrigation are the quantity of water available, the quality of the water and of the soil, the cost of sinking the wells and installing the pumping plants, the cost of pumping, and the value of the crops.

QUANTITY OF WATER.

The amount of available ground water in a given locality is frequently overestimated. Because the existing wells, which are required to furnish only the small supplies needed for domestic or live stock uses, have never shown signs of becoming exhausted, it should not be inferred that any number of wells pumped continuously at a rapid rate will likewise be inexhaustible. Ground water is limited in quantity just as surface water is limited, and heavy pumping will soon develop these limitations even where there was not the slightest indication of them before. The quantity of water that a stream will furnish can be estimated with considerable accuracy on the basis of a series of definite measurements, but no such precise methods can be employed to determine in advance the available quantity of ground water. For this reason projects based on ground-water supplies must be developed with great caution. It is true that ground-water supplies partake of the nature of huge reservoirs filled with water, but figure 5 and the accompanying discussion make it evident that only a small part of these large stores can be recovered without pumping from great depths, which would involve greater expense than can be afforded for ordinary irrigation projects. To be permanently successful a project must not draw from the underground reservoir at a rate much more rapid than that at which the supply is replenished by nature.

In order to obtain the maximum amount of ground water, it is necessary to distribute the wells over the largest area feasible. The amount of water that can be recovered in a given locality is sufficient to irrigate only a small part of the total available land, but the aggregate acreage that could be irrigated annually in these three counties with ground water is no doubt large enough to add substantially to their total agricultural production.

QUALITY OF WATER AND SOIL.

Where water from a stream or spring can be led upon land by means of inexpensive gravity ditches, it may be profitable to use this supply even though the alkali in the water or soil interfere seriously with the crops; but where an expensive pumping plant is required and the water must be lifted by means of power that costs money good crops must be assured. If the cost of producing the crops exceeds their value when sold, the project must obviously come to disaster. Before a pumping plant is installed the water that is to be used and the soil to which it is to be applied should be analyzed, and if the results are not favorable the project should not be carried out. The cost of having the quality of the water and soil investigated is small as compared with the cost of installing and operating a pumping plant.

COST OF PUMPING.

The cost of installation includes the cost of the wells, pumps, engine or other source of power, reservoir and distributing pipes or ditches, and the cost of preparing the land for irrigation.

Where irrigating is done on a small scale windmills can be successfully used, but the amount of water that they will lift is not great, and they are unreliable because they depend on the caprice of the wind. Where windmills are used reservoirs of considerable size should be constructed, and winter irrigation should as far as is feasible be practiced.[1]

For somewhat larger pumping plants gasoline engines furnish a convenient and rather inexpensive source of power. Nine pumping tests were made by Prof. C. S. Slichter in Arkansas Valley, in Kansas, in which gasoline engines ranging in size between 1½ and 10 horsepower were used. In these tests the cost of the gasoline ranged between 12½ and 22 cents per gallon; the total distance that the water was lifted ranged between 15 and 22 feet; and the cost of fuel for pumping one acre-foot of water ranged between $1.09 and $3.75.[2] Fourteen similar tests were made by the same investigator in Rio

[1] See Fuller, P. E., The use of windmills in irrigation in the semiarid West: Farmers' Bull. No. 394, U. S. Dept. Agr., 1910.

[2] Slichter, C. S., The underflow in Arkansas Valley, in western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, pp. 55, 56.

Grande valley with gasoline engines ranging between 5 and 28 horsepower. The cost of the gasoline here ranged between 14 and 17 cents per gallon; the total lift ranged between 24 and 46 feet; the cost of fuel for pumping one acre-foot ranged between $1.04 and $5.80; and the total cost for pumping one acre-foot, including labor, interest on investment, and depreciation, ranged, according to the estimates, between $2.21 and $13.20.[1] It should be understood that the total lift is considerably greater than the normal depth to water because the water level is inevitably lowered as soon as pumping is begun, and also because it is generally necessary to lift the water a few feet above the surface. In a well in which the water level is normally 20 feet below the surface the water may readily be lowered to a level of 30 or 40 feet below the surface when a large pump is operated.[2].

In a discussion of the cost of pumping in Arkansas Valley the following statement is made by Prof. Slichter in regard to gas-producer plants:[3]

> If plants of from 20 to 50 horsepower are constructed, as I believe will inevitably be the case in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines. These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less than one-half cent per horsepower for one hour, or only one-fifth of the cost of power from gasoline at 22 cents a gallon. The writer anticipates no difficulty, therefore, in keeping the cost of water below 60 to 75 cents an acre-foot for fuel, or below $1.25 to $1.50 an acre-foot for total expenses. Hundreds of such plants have been put in use in England during the past ten or more years, and they are in charge of unskilled labor. These gas-producer plants are used in England for a great variety of purposes, such as power for agricultural machinery and for small electric-light plants for country estates, etc. They are used in as small units as 5 horsepower.
>
> In this country the producer-gas plants have been in use for several years, and at the present moment they are fast taking the place of steam power in new plants. The cost of a producer plant and gas engine is about the same as the cost of a steam engine and boiler of the same size if everything is included, but the cost of power from the producer-gas plant is very much less than that obtained from small steam engines.
>
> In producer plants, ranging upward from 100 horsepower, a style of plant may be installed in which soft coal or lignite may be successfully used. This still further cuts down the cost of power. In fact, large plants of this type furnish the cheapest artificial power that has yet been devised. The saving is not only in fuel, but also in labor, as one man is capable of running a 300-horsepower plant.

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[1] Slichter, C. S., Observations on the ground waters of Rio Grande valley: Water-Supply Paper U. S. Geol. Survey No. 141, 1905, pp. 34, 35.

[2] For further information on pumping plants see Gregory, W. B., The selection and installation of machinery for small pumping plants: U. S. Dept. Agr. Exper. Sta. Circular 101, 1910.

[3] Slichter, C. S., The underflow in Arkansas Valley, in western Kansas: Water-Supply Paper U. S. Geol. Survey No. 153, 1906, pp. 57, 58.

Coal that could be used for generating power exists in the mountains of eastern Iron County.[1]

The mountain streams of this region are not large, but have so much fall that they could be used to develop considerable power which could be transmitted by means of electric currents and used for pumping ground water. Several small power plants, used chiefly for electric lighting, have already been installed.

VALUE OF CROPS.

The staple crops of this region are wheat and alfalfa. If more intensive crops, yielding larger returns per acre, could be raised, the cost of pumping could be better afforded, but it is not safe to base calculations on such crops unless it has been established that they can be successfully produced and that there will be a permanent demand for them in the market. As cold air is heavy and therefore tends to sink, the low parts of the valleys and deserts have colder nights than the alluvial slopes or bench lands, and are more liable to have late and early frosts. For this reason fruit raising is not very successful at the lower levels where the ground water is near enough to the surface to be pumped.

The best use of the ground water is probably to supplement the streams, especially since the flow of the latter is very irregular and their water can not easily be stored. In the spring and at other times when the streams are swollen the surplus water, now largely lost, can be applied to fields on the lower parts of the slopes. When, later in the season, the streams are small and none of their water will reach these fields, the growing crops can be irrigated by pumping from wells. By this combination method the ground water, available at the times when most needed, but used only when necessary, will have more than ordinary value, and small amounts will suffice to reclaim relatively large tracts of desert land.

CULINARY WATER SUPPLIES.

Most of the settlements that depend on mountain streams for their irrigation supplies are situated so far up the alluvial slopes that wells can not easily be obtained. Naturally the water for drinking and household use was at first also derived from these streams, and in most places it was drawn from open ditches constructed along the streets. Water from the streams is now generally regarded as unsatisfactory, though it is still used by most of these communities. The domestic animals kept in the settlements roil the water and make it filthy, the flocks of sheep that graze in the mountains impart to it

[1] Lee, W. T., The Iron County coal field, Utah: Bull. U. S. Geol. Survey No. 316, 1906, pp. 359–375. Richardson, G. B., The Harmony, Colob, and Kanab coal fields: Bull. U. S. Geol. Survey No. 341, pp. 379–401.

their characteristic odor, and the heavy rains that occasionally fall in the mountains make it muddy.

The principal danger to health, however, probably does not lie in the pollution from these obvious causes, but in that which results when persons in the mountains become sick with diseases whose germs can be carried by water. It has been demonstrated that in a community using water from a stream an epidemic of typhoid fever can be produced by a single patient suffering with this disease at some point in the drainage basin of the stream. In some localities in this region there have been epidemics of typhoid fever and other enteric diseases, and isolated cases occur after the epidemics are checked. If a person in the mountains is attacked with typhoid fever he is generally ill for some time before he is brought to a settlement and placed in care of a physician. While he is in the mountains his excreta, burdened with typhoid germs, are usually not disinfected and can easily be washed into a stream that furnishes the drinking supply for a settlement below. This disease is no doubt spread by other agencies, a discussion of which is not within the province of this paper, but there is evidence that pollution of the water supplies is an important cause of its prevalence.

Spring waters sufficient for a public supply and high enough to be led by gravity through pipe lines are found within a few miles of nearly every village situated on an alluvial slope. Waterworks supplied from springs have already been installed at Nephi and Holden and are being planned for Cedar City, Fillmore, and other towns. In most places the expense of installing such a system of waterworks is heavy when compared with the financial resources of the community, but its value in furnishing a convenient, clear, and wholesome supply of water would be great. In general the plans that are being considered do not provide for fire protection, which would involve an additional cost for a reservoir and large mains leading from it. Springs used for public supplies should of course be carefully guarded against contamination of any sort.

Several of the settlements, such as Scipio, Meadow, and Hatton, are situated on relatively low ground, where water is found by digging to moderate depths. Here open wells furnish most of the supplies for drinking and household uses. Their water may be contaminated by privies near the wells or by other sources of pollution, but it is generally less dangerous to health than the stream water. Safer supplies could be obtained by drilling to deeper water-bearing beds of sand or gravel and finishing the drilled wells with tight iron casings to shut out the surface pollution.

In the settlements along Sevier River nearly the entire domestic supply is obtained from wells. Most of these wells consist of small drilled holes with iron casings 2 inches or less in diameter. Where

the casing extends to the surface and the water overflows there is little or no chance of pollution. Where the water remains some distance below the surface, as at Abraham and Burtner, but is allowed to discharge into a dug pit, there is more chance for pollution unless the pit is made water-tight. Where the casing is large enough and the water is yielded rapidly enough the danger of pollution can be diminished by extending the casing to the surface and pumping from inside of it. At Leamington there are shallow dug wells, but water from Sevier River is also used. The water in the dug wells is liable to be somewhat polluted, but it is less dangerous to health than the river water. The latter should not be used for drinking.

At Silver City, Robinson, and Mammoth the water supplies are brought through pipe lines from distant mountain springs, and with ordinary precautions they ought to be pure and wholesome. The supplies for Eureka are in part conveyed through pipe lines from shallow wells in the Homansville Basin and in part drawn from shallow private wells in the city. Many of the private wells are so situated that they are dangerously exposed to pollution. With proper care the Homansville water can be protected, but contaminating agencies, such as slaughterhouses, should not be tolerated in this basin.

SUPPLIES FOR DRY FARMS.

On the dry farms water is required for culinary purposes and for the horses and traction engines used in tilling the soil and harvesting the crops. Many of these farms have been established high up on the alluvial slopes or on other so-called bench lands, where large tracts of fertile soil, free from alkali, have hitherto remained unused. Many of these elevated tracts are without water supplies and the water used on the dry farms is hauled long distances.

The rainfall data indicate that most of the region considered is too arid for agriculture without irrigation and that dry farming will be restricted practically to the eastern valleys. As these valleys have comparatively abundant rainfall and most of them receive mountain streams their ground-water prospects are comparatively good. It seems probable that in most localities where dry farming is practiced adequate supplies of fairly good water can be procured from wells within convenient distances of the fields that are cultivated.

Where the unconsolidated sediments are known to be saturated to the level of the low areas, such as Juab, Little, Round, Pavant, Parowan, Rush Lake, and Tintic valleys, water can generally be obtained by sinking wells higher up on the bench lands than has thus far been done, but the holes must be put down to depths of several hundred feet, and the water will have to be lifted from considerable depths beneath the surface. Positions not too high and as far as possible from the margins of the mountains, or from any outcropping

rocks, should be selected for wells, otherwise the water may be reached at depths from which it can not be conveniently lifted, or barren bed rock may be struck before any water is found.

Prospecting for wells in these localities can be done better with drilling machines than by digging. The type of drill best adapted for this kind of work is discussed on page 59. By ascertaining the difference in altitude between the point where the drilling is to be done and the nearest successful well in the valley, some conception can be obtained of the probable depth to water. Generally, drilling should not be undertaken where this difference is more than several hundred feet.

If casing not less than 4 inches in diameter is used, there will be no special difficulty in lifting enough water for dry-farm purposes from depths of 200 to 300 feet, or even more. A deep-well pump should be used which is entirely independent of the casing and whose cylinder and valves are near the bottom of the well. The pump rod will occasionally break, because it will unavoidably wear against the inside of the pump pipe. On account of the high lift the valves must be kept in good condition. Repairing the pump rod or valves in a deep well involves no great expense, but generally requires the labor of several men for a few hours.

Certain arable tracts, such as lie between Juab and Tintic valleys and in the region southwest of Kanosh, are so elevated and in many places appear to have rock so near the surface that it is doubtful whether available water exists there in the unconsolidated sediments, while drilling into rock is an expensive and uncertain undertaking.

In Tintic Valley the alluvial slopes are so high and so much dissected that only the lower parts of these slopes have good prospects.

On most of the Lynn bench the conditions are favorable for obtaining satisfactory wells by sinking to moderate depths.

SUPPLIES FOR THE RANGE.

In the extensive tracts which are too arid for agriculture of any kind, but which have a certain value for grazing, water supplies are needed for live stock, but so great is the aridity that watering places are scarce and even small supplies of poor water are highly prized. Parts of the region are so far from any supply that they can be used for grazing only in winter when there is snow on the ground.

The prospects of getting wells are of course much poorer here than in the less arid dry-farming districts. In upland areas, such as the country lying between Sevier Lake and Snake Valley or the extensive bench lands east of the Confusion and House ranges and west of the Thomas and Fish Springs ranges, the chances are strongly against finding ground water.

Wells that would furnish valuable supplies for live stock, however, would probably be successful in certain localities now destitute of water supplies. Such localities exist in Sevier Desert north of the Desert Wells, in the Old River Bed region, in the low parts of White Valley, and possibly in the bottoms adjacent to Sevier Lake and the lowest part of Wah Wah Valley. Wells should not be located either far up on the slopes or far out on the flats, but on intermediate low ground near the base of the slopes. The larger, steeper, and more gravelly the slope or bench and the more extensive the drainage area that pours its freshets over it, the better the chances of obtaining water. In these localities rather thorough explorations for ground water can be made without expensive drilling, for the formations encountered will almost invariably consist of unconsolidated sediments that are not difficult to penetrate, and if bedrock should be struck it would probably be unwise to drill into it. Moreover, if properly located, a hole a few hundred feet deep will give a fair test.

Iron County is better supplied with watering places than Juab and Millard counties, and this fact gives it a distinct advantage in raising live stock. The small springs in the western mountains are utilized and a number of stock wells have been sunk in different parts of Escalante Desert. The value of these wells is great in comparison with their cost.

BOILER SUPPLIES.

As this region contains no manufacturing towns, boiler supplies are not of primary importance, but such supplies are needed for the traction engines on the dry farms, for the stationary engines at the mines, and for the locomotives on the railroads.

In endeavoring to procure locomotive supplies of adequate quantity and satisfactory quality at proper intervals along the San Pedro, Los Angeles & Salt Lake Railroad many difficulties were encountered. On the main line supplies are now provided at Tintic Junction and Jericho (in Juab County), at Lynn, Oasis, Goss, and Black Rock (in Millard County), and at Lund, Beryl, and Modena (in Iron County). At Tintic Junction the supply is taken from the Cherry Creek pipe line; at Jericho it comes through small pipes from a number of springs from 3 to 4½ miles distant; at Lynn it is drawn from a well that furnishes a large amount of good water; at Oasis it is also obtained from a well, but the water is less desirable for boiler use than that at Lynn; at Black Rock a supply of good water is derived from the springs near the station; at Lund and Beryl the supply is obtained from wells that furnish water of satisfactory quality; and at Modena the supply is obtained through a pipe line from springs or wells a short distance from the station.

The greatest difficulty was experienced between Oasis and Black Rock. An old well at Clear Lake and the more recently drilled wells

at Neels and Goss all yielded highly mineralized water. The wells at Clear Lake and Neels have been abandoned, but the water from the Goss well is used in locomotives when necessary, although it is salty.

In addition to being used in locomotives, the railroad supplies are largely relied upon for domestic purposes by the people who live at the stations, there being no other water at several of the inhabited points. At Clear Lake the drinking and culinary supplies are taken from a reservoir into which water is hauled by the railroad company.

On the branch line of the San Pedro, Los Angeles & Salt Lake Railroad that passes through Juab Valley good locomotive supplies are obtained from a flowing well at Starr and a spring near Juab.

The Rio Grande Western Railroad Co. has a locomotive supply at Eureka, the water being derived from shallow wells.

CONSTRUCTION OF WELLS.

TYPES OF WELLS IN USE.

Four kinds of wells are found in this region: (1) Ordinary dug wells; (2) small cased wells; (3) large drilled wells; and (4) large open wells with infiltration galleries.

The dug wells, which are the most common type, are found on the flats and on the lower parts of the alluvial slopes. They are sunk only a few feet below the level at which water is struck and are rarely more than 100 feet deep. Their construction requires considerable labor but costs little otherwise for they are seldom curbed above the water level and the water is generally drawn with a bucket attached to a rope.

The small cased wells are found in the flowing areas and in parts of Sevier Desert where flows are not obtained but where the shallow ground water is salty while the deeper water is of good quality. They are sunk where it is desirable to shut out the first water encountered and to tap deeper horizons—either because the deeper water is under greater pressure or is of better quality. The casing, which consists of iron pipe, is ordinarily between 1 and 2 inches in diameter. Since these wells are sunk only in the low areas where the sediments penetrated consist of clay and sand with rarely any bowlders or large gravel, they can be drilled rapidly by the jetting or hydraulic process with a light and inexpensive rig. Where the water does not rise to the surface by artesian pressure it is customary to have a so-called "pit flow," a hole being dug to such a depth that the water from the deep stratum, coming up through the casing, will overflow into the hole, from which it is brought to the surface by a pump or other lifting device.

A number of deep wells of larger diameter have also been drilled. Some of these were put down by the railroad company; others were test wells sunk by the State of Utah; and still others were oil prospects sunk by different concerns.

The large dug wells with tunnels or infiltration galleries are a special type adapted to special conditions. They are found chiefly at Eureka and Homansville where it is important to obtain as large supplies as possible from the meager seepage out of the decomposed igneous rock and overlying loose waste.

DRILLED WELLS ON ALLUVIAL SLOPES.

The wells on the alluvial slopes are, almost without exception, of the dug type, but in some respects drilled wells with iron casing 4 to 6 inches in diameter would be better adapted to the conditions. They could easily be sunk to greater depths than the dug wells and thus they would frequently find water where the dug wells are failures. They would not, like the dug wells, end in the first water-bearing bed encountered, which is generally weak, but could be carried to deeper horizons where large supplies would be found. They would also be better protected from pollution and would therefore furnish cleaner and safer water for drinking and culinary use. If the labor required in digging a well is not considered, a dug well is, of course, much less expensive than a drilled one would be, but if the labor were paid for at a fair wage the dug well would probably not be cheaper. Since the digging is frequently done at times when there is no other work, the actual cost of many of the dug wells is not great. For drilling on the bench lands the light jetting rigs used on the flats would not be adequate, but heavy rigs, such as are used in sinking oil wells, are not necessary. A portable rig with cable and 4-inch or 6-inch percussion drill, built to go to depths of several hundred feet, will be serviceable for this kind of work. Such a machine can be purchased at a moderate price and operated with only moderate expense. If bowlders too large to be pushed aside by the drill are struck it may be possible to shatter them by the use of explosives, or, if the drilling has not progressed far, a new hole can be started with no great loss of time.

"PIT FLOWS."

In the so-called "pit-flow" wells, the pit must be dug to the surficial ground-water level or somewhat lower. Unless these pits are made water-tight by means of cement curbs, they may admit salty water that in some places occurs near the surface, or bacteria-laden organic matter from nearby privies or other sources of pollution. The iron casing that extends to the deeper water is in most wells of

so small diameter that a pump placed inside of it would not give satisfactory service, but if wells with somewhat larger casing (perhaps 4 inches in diameter) were made, the casing could be brought to the surface and a pump hung inside of it, thus dispensing with the pit. Where the water level is at a considerable distance below the surface these wells of larger diameter would probably not be more expensive than the small wells when the cost of the cement curb for the pit is included.

IRRIGATION WELLS.

Wherever irrigation with ground water is undertaken wells of large diameter should be drilled. These wells should be drilled deep enough into the unconsolidated sediments to tap water-bearing beds that have not been reached in ordinary drilling, and they should admit water at as many levels as practicable. Since in the localities where the ground water is near the surface the unconsolidated sediments are easily penetrated with a drill, and since rock drilling is not involved, the difficulty of making these larger irrigation wells will not be as great as might be supposed. With the proper type of machine and with some experience in operating it, the work can be done rapidly and with few mishaps. The adoption of better methods than now prevail will lead to lower costs and to larger yields from both flowing and pumped wells, and may make practicable the development of ground waters in areas where their development is now impracticable.

THE CALIFORNIA OR "STOVEPIPE" METHOD OF WELL CONSTRUCTION.

In California, where irrigation water is very extensively drawn from unconsolidated valley-fill material similar to that in which most of the valuable Utah ground waters occur, a special type of well has been evolved. In the belief that the California method of well construction can be used with advantage in the valleys of Utah, the following description is quoted from a paper by Charles S. Slichter:[1]

CONDITIONS IN CALIFORNIA.

The valleys in southern California are filled with deposits of mountain débris, gravels, sands, bowlders, clays, etc., to a depth of several hundred feet, into which a considerable part of the run-off of the mountains sinks. The development of irrigation upon these valleys soon became so extensive that it was necessary to supplement more and more the perennial flow of the canyon streams by ground water drawn from wells in the gravels. This necessity was greatly accentuated by a series of dry years, so that ground waters became a most valuable source of auxiliary supply for irrigation in the important citrus areas in southern California. The type of well that came to the front and

[1] The California or "stovepipe" method of well construction: Water-Supply Paper U. S. Geol. Survey No. 110, 1905, pp. 32–36.

developed under these circumstances is locally known as the "stovepipe" well. It seems to suit admirably the conditions prevailing in southern California. In procuring water for irrigation the item of cost is, of course, much more strongly emphasized than in obtaining water for municipal use. The drillers of wells in California were not only confronted with a material which is almost everywhere full of bowlders and similar mountain débris, but also by a high cost of labor and of well casings. It was undoubtedly these difficulties that led to the very general adoption in California of the "stovepipe" well.

DESCRIPTION OF APPARATUS AND METHODS.

The wells are put down in the gravel and bowlder mountain outwash or other unconsolidated material to any of the depths common in other localities. One string of casing in favorable location has been put down over 1,300 feet. The usual sizes of casings are 7, 10, 12, and 14 inches, or even larger. A common size is 12 inches. The well casing consists of, first, a riveted sheet-steel "starter," from 15 to 25 feet long, made of two or three thicknesses of No. 10 sheet steel, with a forged steel shoe at lower end. In ground where large bowlders are encountered these starters are made heavier, the shoe 1 inch thick and 12 inches deep, and three-ply instead of two-ply No. 10 sheet-steel body.

The rest of the well casing, above the starter, consists of two thicknesses of No. 12 sheet steel made into riveted lengths, each 2 feet long. One set of sections is made just enough smaller than the other to permit them to telescope together. Each outside section overlaps the inside section 1 foot, so that a smooth surface results both outside and inside of the well when the casing is in place, and so that the break in the joint is always opposite the middle of a 2-foot length. It is these short overlapping sections which are popularly known as "stovepiping."

The casing is sunk by large steam machinery of the usual oil-well type, but with certain very important modifications. In ordinary material the "sand pump" or "sand bucket" is relied upon to loosen and remove the material from the inside of the casing. The casing itself is forced down, length by length, by hydraulic jacks, buried in the ground, and anchored to two timbers 14 by 14 inches and 16 feet long, which are planked over and buried in 9 or 10 feet of soil. These jacks press upon the upper sections of the stovepiping by means of a suitable head. The driller, who stands at the front of the rig, has complete control of the engine, the hydraulic pump, and the valves by which pistons are moved up or down, and also of the lever that controls the two clutches which cause tools to work up and down or to be hoisted.

The sand pumps used are usually large and heavy. For 12-inch work they vary in length from 12 to 16 feet, are $10\frac{5}{8}$ inches in diameter, and weigh, with lower half of jars, from 1,100 to 1,400 pounds.

After the well has been forced to the required depth, a cutting knife is lowered into the well and vertical slits are cut in the casing where desired. A record of material encountered in digging the well is kept and the perforations are made opposite such water-bearing materials as may be most advantageously drawn upon. A well 500 feet deep may have 400 feet of screen if circumstances justify it.

The perforator (see fig. 6) for slitting stovepipe casing is handled with 3-inch standard pipe with $\frac{3}{4}$-inch standard pipe on the inside. In going down or in coming out of the well the weight of the $\frac{3}{4}$-inch line holds the point of the knife up. When ready to "stick" the $\frac{3}{4}$-inch line is raised. By raising slowly on the 3-inch line with hydraulic jacks, cuts are made from three-

eighths to three-fourths inch wide and from 6 to 12 inches long, according to the material at that particular depth. In another type of perforating apparatus (fig. 7) a revolving cutter punches fine holes at each revolution of the wheel. This style of perforator is called a "rolling knife." Besides these many other kinds of perforators are in use in California. In fact, the perforator is a favorite hobby of the local inventors. They all seem to work well.

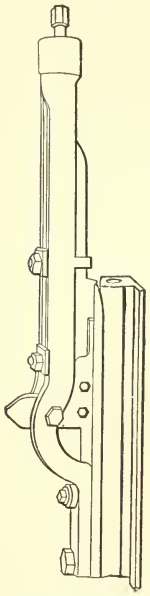


FIGURE 6.—Perforator for slitting stovepipe casing.

ADVANTAGES OF CALIFORNIA METHOD.

The advantages of this method of well construction are quite obvious. For wells in unconsolidated material, the California type is undoubtedly the best yet devised. * * *

Among the special advantages in the stovepipe construction we may enumerate the following:

1. The absence of screw joints liable to break and give out.

2. The flush outer surface of the casing, without couplings to catch on bowlders or to hang in clay.

3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.

4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.

5. The cheapness of large-size casings, because made of riveted sheet steel.

6. The advantage of short sections, permitting use of hydraulic jacks in forcing casing through the ground.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife are the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

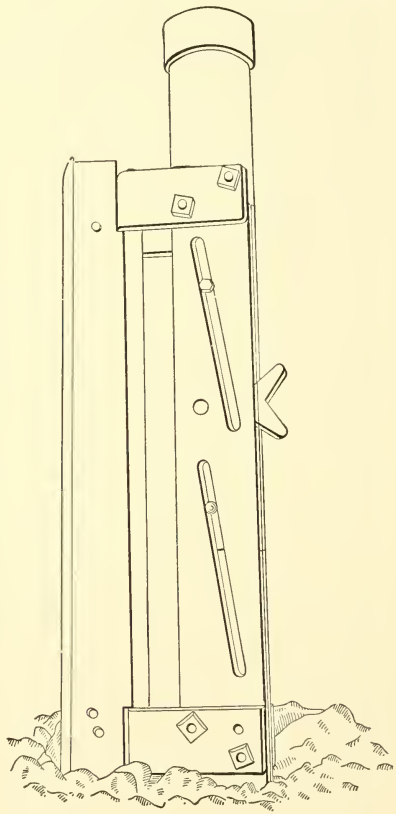


FIGURE 7.—Roller type of perforator.

9. The large size of casing possible in this system permits a well to be put down in bowlder wash where a common well could not possibly be driven.

10. The uniform pressure produced by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system relying upon driving the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig, as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in, and by the cheap form of casing.

COST OF THE WELLS.

An idea of the cost of constructing these wells can best be given by quoting actual prices on some recent construction in California. According to contracts recently let near Los Angeles, the cost of 12-inch wells was:

Fifty cents per foot for the first 100 feet, and 25 cents additional per foot for each succeeding 50 feet, casing to be furnished by the well owner. This makes the cost of a 500-foot well $700 in addition to casing. The usual type of No. 12 gauge, double stovepipe casing, is about $1.05 a foot, with $40 for 12-foot starter with ¾-inch by 8-inch steel ring. A good driller gets $5 a day; helpers, $2.50 a day. The cost of drilling runs higher than that given above in localities where large and numerous bowlders are encountered.

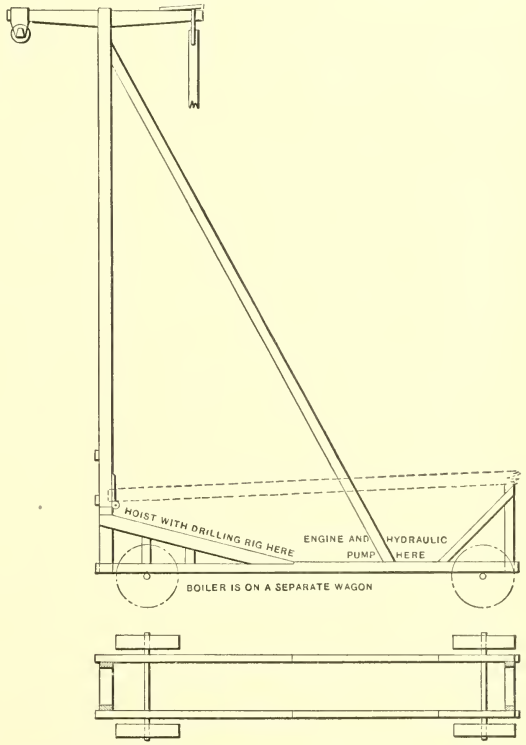


FIGURE 8.—Common form of California well rig.

The drillers build their own rigs according to their own ideas, so that no two rigs are exactly alike; that is, the drillers pick out the castings and working parts and mount them according to ideas that experience has taught them are the best for the wash formations in which they must work. Figure 8 shows a common form of rig.

It is not very profitable to name individual wells of this type and give their flow or yield, since conditions vary so much from place to place. From the method of construction it must be evident that this type of well is designed to give the very maximum yield, as every water-bearing stratum may be drawn upon. The yield from a number of wells in California of average depth of about 250 feet, pumped by centrifugal pumps, varied from about 25 to 150 miners' inches, or from 300,000 to 2,000,000 gallons a day. These are actual measured yields of water supplied for irrigation.

Among the very best flowing wells in southern California are those near Long Beach. The Boughton well, the Bixby wells, and the wells of the Sea

Side Water Co. are 12-inch wells, varying in depth from 500 to 700 feet and flowing about 250 miners' inches each, or over 3,000,000 gallons per 24 hours. The flow of one of these wells is the greatest I have seen reported. Among the records for depth are those of 1,360 feet for a 10-inch well, and 915 feet for a 12-inch well. A new 14-inch well has already reached a depth of 704 feet.

WATERING PLACES ON ROUTES OF TRAVEL.

The following information is given for the benefit of persons who are strangers to this region but who wish for any reason to make a journey to some part of it. In connection with these directions, Plates I, II, and IV should be consulted. It should be remembered that changes are made from time to time and that wells in use at one time may later become filled up. For this reason inquiries should be made from local sources before starting on a trip.

RAILWAY STATIONS AND THEIR CONNECTIONS.

On the maps of this region stations are indicated at intervals of several miles along the railroad, but most of these stations are merely switches, with no inhabitants and no shelter, food, or water.

Eureka, Robinson, and Silver City are mining towns where conveyances and provisions for a journey can be procured. Mona, Nephi, Juab, and Leamington are villages situated on the branch railroad that joins the main line at Lynn. Juab is the supply station for Levan and also has stage connections with Scipio. Leamington is a convenient station from which to reach Oak City. Lynn is a small railroad town where it may not be possible to outfit for a journey.

South of Lynn the inhabited stations on the main line which supply the region east and west are Akin (Burtner), Oasis, Clear Lake, and Black Rock, in Millard County; Milford, in Beaver County; Lund and Modena, in Iron County.

Oasis is the principal supply station for middle and lower Snake Valley, and is a good outfitting point for a journey to the western parts of Juab and Millard counties. Oak City and Holden can also be reached from this station. A stage goes twice each week to Joy and freighters make regular trips to Fish Springs.

Clear Lake is the principal supply station for Pavant Valley. A stage goes daily to Fillmore, whence there are stage connections with Meadow and Kanosh, and also with Holden and Scipio.

Milford is a mining town and also the supply station for Beaver and the other settlements of eastern Beaver County. From this point a branch railroad goes to Frisco and Newhouse, both of which are mining towns. From Newhouse there is a stage line to Garrison, in Snake Valley.

Lund is the supply station for Rush Lake and Parowan valleys. A stage runs daily to Cedar City, from which there are stage connec-

tions with the other settlements in these valleys, and indirectly with Sevier Valley. A halfway house between Lund and Cedar City is situated at Iron Springs.

Modena is the supply station for settlements in Washington County and for Gold Spring, Stateline, and Fay—small mining camps northwest of Modena. There are stage connections in both directions.

TINTIC MINING DISTRICT TO SEVIER DESERT AND JOY.

The road leading from the Tintic district south to Leamington or Lynn runs near the central axis of Tintic Valley. A good watering place along this road is McIntyre's ranch, in the center of the valley and a short distance west of McIntire station. Water can perhaps also be procured at Jericho station or at some other point in the valley.

In going to Joy or points beyond, water can be obtained along Cherry Creek, preferably at Rockwell's ranch (NE. ¼ sec. 30, T. 12 S., R. 5 W.). The only permanent water supply between Rockwell's and Joy is at the Hot Springs, which are reached by leaving the main road and following a road that leads southward along the east side of the lava plateau. Since the water from these springs is too highly mineralized to be fit for man to drink, it is usually wisest to drive directly to Joy.

From Rockwell's, a road leads to Abraham and another to Oasis. Along the first there is no water until near Abraham; the second passes the Desert wells, where water can be procured.

OASIS TO JOY, FISH SPRINGS, AND DEEP CREEK.

The trip from Oasis to Deep Creek is best made by way of Joy, Fish Springs, and Callao, but it can be made also by way of Antelope Spring, Trout Creek, and Callao.

Joy can be reached by way of Abraham or by way of the Old Smelter well and the road between Drum and Little Drum Mountains. On the Abraham route plenty of good wells are found between Oasis and Abraham, but the last watering place before reaching Joy is a well a short distance northwest of Abraham, at the buildings on the farm of Peter Christensen (SW. ¼ SE. ¼ sec. 15, T. 16 S., R. 8 W.). On the other route the Old Smelter well, 15 miles northwest of Deseret, is used by the freighters, but it can not be relied upon for a water supply unless specific information to that effect is obtained. The next watering place after leaving the Old Smelter well is at Joy, where there are two wells.

In going from Joy to Fish Springs the road shown in Plate IV is followed. The first watering place after leaving Joy is at Cane

Spring, which furnishes water of poor quality that is used, however, by the freighters for their horses. Six or seven miles farther north is Thomas's ranch, where there is plenty of good water. At the Utah mine, on the west slope of the Fish Springs Range, water elevated from the mine is used for both man and beast.

Between the Utah mine and Callao there is no water, but at the latter point there are good wells and springs. From Callao a road leads northward and westward across the mountains to the settlement in the valley of Deep Creek.

From the Utah mine or Callao the middle and upper parts of Snake Valley can be reached by way of Trout Creek, where there are two ranches with a good water supply. There is no dependable watering place between these points and Trout Creek.

STAGE ROUTE TO FISH SPRINGS AND DEEP CREEK.

A stage goes from Ajax, in Tooele County, to Dugway, Thomas's ranch, the Utah mine, Callao, and Deep Creek, but this route has few watering places. Dugway (between the Dugway and Thomas ranges) is uninhabited most of the time and has no reliable water supply.

OASIS TO SNAKE VALLEY.

The middle part of Snake Valley is most conveniently reached from Oasis, the road leading west across the House Range, White Valley, and the Confusion Range, as shown in Plate IV. After leaving the settlements the first watering place is Antelope Spring, on the House Range, and the second is one of the springs in White Valley. In White Valley the road forks, one branch leading to Trout Creek, another to Foote's ranch, and another to Meecham's ranch and Garrison. The first watering places reached on these routes after leaving the springs of White Valley are, respectively, at Trout Creek, Bishop's Springs (near Foote's ranch), and Knoll Springs. In Snake Valley, from Trout Creek to Garrison, Burbank, and Big Springs, watering places exist at no great distances apart.

NEWHOUSE TO SNAKE VALLEY.

Newhouse is a mining town in Beaver County, at the terminus of a branch railroad that extends west from Milford. (Figs. 1 and 2.) From this point a stage is run west-northwest to Burbank and Garrison. On the route followed by the stage water can usually be procured at Kelley's, which is on the west side of Wah Wah Valley, opposite Newhouse. A short distance south of Kelley's are the Wah Wah Springs, the water from which is conveyed through a pipe line to Newhouse. Between Kelley's and Burbank there is no watering place.

BLACK ROCK AND CLEAR LAKE TO SNAKE VALLEY AND IBEX.

Snake Valley is more easily reached from Oasis or Newhouse than from Black Rock or Clear Lake. In making the trip from Black Rock it is best to go first to Newhouse or Kelley's and thence follow the stage road to Burbank. There is no watering place between Black Rock and Newhouse or Kelley's.

Ibex, a winter supply station for sheep herders, is situated a few miles west of the southern extremity of White Valley, about 35 miles by wagon road from Black Rock and 50 miles from Clear Lake. It is on unsurveyed land in T. 22 S., R. 14 W., and, as nearly as was ascertained, its location in this township is about midway between the north and south lines and a little over a mile from the west boundary. The water supply, which consists of rain or melted snow stored in small rock reservoirs, is not permanent and should not be depended on unless specific and reliable information is received in regard to it before the journey is undertaken. There is no water between Black Rock and Ibex. In going from Clear Lake to Ibex, water can be procured at the flowing well on the Swan Lake farm (6 miles from Clear Lake station) and also at the headquarters of the farm (on the banks of Sevier River, about 10 miles from the station). There is no water between the river and Ibex, and none between Ibex and Garrison.

JUAB VALLEY.

TOPOGRAPHY AND GEOLOGY.

Juab Valley is bounded on the east by a precipitous and imposing rock wall, formed in the northern part by the southernmost extension of the Wasatch Mountains and farther south by the San Pitch Mountains. (See Pl. I.) This section of the Wasatch Mountains is in the main a huge anticlinal fold, flanked on the west by steeply dipping strata, chiefly Carboniferous limestone.[1] It culminates in Mount Nebo, which projects to an elevation of 11,887 feet above the sea and towers 7,000 feet above the center of the valley less than 5 miles distant. The San Pitch Mountains contain younger formations and are capped by early Tertiary strata.

On the west the valley is bordered by a low but continuous range, back of which lie loftier mountain masses. This range consists of Paleozoic limestones, overlain to the north by igneous rocks and to the south by a series consisting chiefly of red and yellow conglomerate and sandstone, probably early Tertiary in age. This series dips steeply eastward and pitches toward the south.

The valley constitutes a structural trough continuous, in a sense, with Sevier Valley to the south and Utah Valley to the north, from

[1] Emmons, S. F., U. S. Geol. Survey, 40th Par., vol. 2, 1877, pp. 343, 344.

each of which it is separated by a low débris-covered divide. It is filled to an unknown depth with material washed from the mountain borders. It contains a north basin and a south basin, which are separated from each other by a broad, gentle elevation commonly known as the Levan Ridge (fig. 9). The north basin belongs to the Great Salt Lake drainage area and the south basin to the Sevier River drainage area. The surface water in each has an avenue of escape from the valley, not by way of the low divide at either end, but through a gorge cut into the rock of the west wall. The swampy and alkali conditions show, however, that in recent time the drainage out of the valley has not been vigorous.

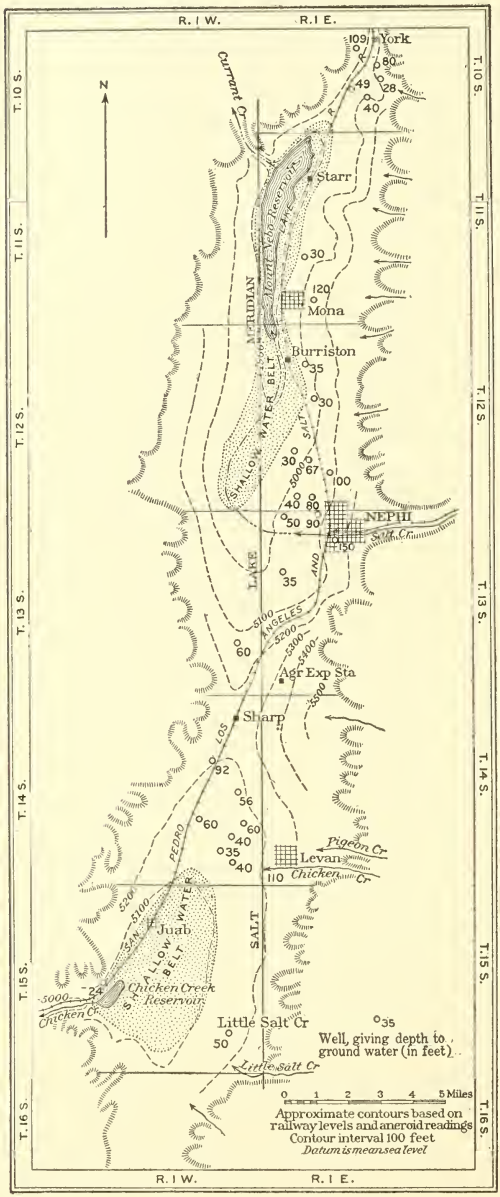


FIGURE 9.—Map of Juab Valley, Utah, showing ground-water conditions.

RAINFALL.

According to the records of the United States Weather Bureau, the precipitation is greater in Juab Valley than in any other section discussed in this report. (See p. 19 and fig. 3.) At Levan, where observations have longest been made, the average annual rainfall for the last 16 years was 16.58 inches, approximately 40 per cent of which fell in the spring, 13½ per cent in the summer, 20 per cent in the fall, and 26½ per cent in the winter. (See fig. 4.) In recent years considerable success has been attained with dry farming. The principal product is winter wheat, and the usual method is to en-

deavor to raise a crop only in alternate years.[1] The abundant spring rains favor this method of agriculture, but the dry season which usually begins in June is adverse, especially for the late crops.

Precipitation (in inches) in Juab Valley.

Levan.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1892	1.29	0.55	2.90	1.68	1.85	0.47	0.20	0.02	Tr.	.....	0.60	2.38	.....
1893	1.28	.98	3.42	2.69	1.12	.00	.40	1.68	1.17	.20	.96	1.85	15.75
1894	1.70	1.55	1.20	2.30	.96	1.71	.95	.89	2.87	.85	.00	2.75	17.73
1895	1.60	2.20	3.50	5.10	7.18	.28	.84	1.04	.91	.89	1.63	.95	26.12
1896	1.16	.60	1.49	1.23	1.58	.36	2.26	.71	.54	.50	1.58	.36	12.37
1897	1.95	1.88	2.22	1.05	.85	.41	.28	.14	1.84	3.29	1.23	1.65	16.79
1898	.80	.25	1.45	1.06	5.57	.90	1.62	.73	.00	.99	.94	1.36	15.67
1899	1.43	2.25	3.96	.71	1.75	.95	.25	1.06	.00	2.07	1.09	1.91	17.43
1900	.87	.70	.12	3.70	.57	.04	.03	.28	1.70	.69	1.45	.19	10.34
1901	.93	2.23	1.88	1.02	1.74	.29	.25	1.55	.18	1.31	.53	1.40	13.31
1902	.53	1.41	2.41	1.20	.16	.03	.32	.20	.91	1.62	1.98	1.72	12.49
1903	1.64	.98	1.33	2.03	2.26	.48	.47	.15	.92	1.56	.24	.52	12.58
1904	1.71	1.93	3.25	1.00	3.13	.44	.79	1.24	.27	.98	.00	1.52	16.26
1905	.91	2.53	2.10	1.03	2.60	.30	.34	.47	3.68	.12	1.22	.94	16.24
1906	1.64	1.37	5.69	3.77	3.30	.57	.79	1.31	1.74	.38	1.57	1.71	23.84
1907	3.04	2.70	1.21	1.19	2.33	1.35	.43	3.57	.91	1.11	.36	1.89	20.09
1908	.82	1.19	1.00	.31	4.35	1.15	1.06	1.55	2.89	1.87	.63	1.40	18.22
Average	1.37	1.49	2.30	1.83	2.43	.57	.66	.98	1.21	1.15	.94	1.44	16.58

Nephi.

1904	.....	.....	.....	.....	.....	0.43	0.94	0.07	0.18	1.07	0.00	1.10	.....
1905	.79	1.85	2.60	1.72	1.71	.26	.37	.49	2.86	.05	1.23	.69	14.62
1906	1.62	1.07	4.29	3.76	3.35	.61	1.45	2.31	.71	Tr.	1.81	1.36	22.34
1907	1.82	2.27	2.26	1.28	2.13	1.30	.98	1.98	.64	.67	.66	2.01	18.00
1908	.79	1.21	1.28	.44	4.46	1.23	.61	1.31	2.62	1.63	.66	.60	16.84

STREAMS.

Juab Valley receives the drainage of about 500 square miles, somewhat more than one-half of which belongs to the north basin. Most of this area is mountainous country which lies east of the valley and gives rise to the creeks that furnish the irrigation supplies. The low ridge to the west has no springs of consequence and gives rise to no permanent streams.

Salt Creek, the largest stream, heads far back in the mountains, receives the drainage from the east side of Mount Nebo, flows through a canyon between the Wasatch Mountains and San Pitch Mountains, and enters the valley at Nephi, which it supplies with water for irrigation. North of Salt Creek a number of small streams issue from the high mountains and furnish irrigation supplies for ranches and small settlements that extend from Nephi to the north end of the valley. The surplus water that reaches the lowest part of the basin is there stored, and is eventually led, through the canyon that forms the north outlet of Juab Valley, into Goshen Valley, where it is utilized for irrigation. (See fig. 9.)

[1] Farrell, F. D., Dry-land grains in the Great Basin: U. S. Dept. Agr., Bur. Plant Industry, Circular 61, 1910.

The largest streams tributary to the south basin are Chicken Creek and Pigeon Creek, which provide the irrigation supplies for the settlement of Levan. Farther north Fourmile Creek, a small stream, flows out upon the Levan Ridge, where it supplies a ranch and a dry farm. About 8 miles south of Levan, Little Salt Creek enters the valley and furnishes irrigation water for a few families, and near the south divide a small stream debouches from Chriss Canyon. The surplus water in the south basin is utilized in much the same manner as that in the north basin. It is stored in a reservior in the low central flat, whence it is led, through the south outlet of Juab Valley, upon lower ground in Little Valley. (See fig. 9.)

SPRINGS.

In the north basin a chain of seepage springs extends along the foot of the east slope, which receives the principal supply of water from the mountains. In the south basin an important group of springs occurs on the farm of Arthur Meads (NW. ¼ sec. 2, T. 15 S., R. 1 W.), at the foot of the alluvial fan of Chicken Creek. It is probably fed largely by the irrigation waters applied to the Levan fields.

The springs in both basins are employed to some extent for irrigation, but much of the water goes to waste or is used to poor advantage on low-lying grass lands. Water from Meads's Spring is led by gravity through a pipe line to the railway tank at Juab station and is there used for locomotive supplies.

The discharge of some of the springs varies notably with the different seasons, the yield being greatest from July to October, and least in the latter part of winter. This fluctuation shows that the ground water responds to the seasonal variations in precipitation, but with a lag of several months, for the heaviest rainfall and the largest supplies from the melting of the snow in the mountains occur in the spring while the least precipitation is in the summer.

FLOWING WELLS.

In the low central part of the north basin (Pl. I) numerous flowing wells are found for a distance of about 12 miles, from a point north of Starr nearly to a point in the valley due west of Nephi. The position of most of these wells on the east side of the central axis is due chiefly to the fact that the principal ground-water supply comes from the east, but is probably in part also due to the fact that the ranches and settlements are on the east side and therefore most of the drilling has been done there. The flowing wells range in depth from about 80 feet to somewhat more than 300 feet, and without doubt all are supplied from beds of sand and gravel in the valley fill. Nearly all are 2 inches or less in diameter, and their natural flow

ranges from a fraction of a gallon a minute to a maximum of about 30 gallons a minute. Their yield is said to vary in a manner somewhat like that of the springs, the largest discharge being in summer and fall, and the smallest in the latter part of winter. Several wells near the margin of the area of flow are so sensitive to climatic conditions that they may cease to flow during or immediately after dry seasons. The locomotive supply at Starr is furnished by a 1½-inch flowing well from which the water rises into the tank by artesian pressure.

The low central tract of the south basin is somewhat wider but not nearly as long as that of the north basin, and its ground-water resources have been less thoroughly explored. Until recently the only flowing well in this basin was that of N. M. Taylor, at Juab. This well is 2 inches in diameter and 130 feet deep and discharges several gallons per minute. It is situated on relatively low ground, but it is west of the center of the valley and rather remote from the east slope which is the main source of water supply. The water rises to at least the level of the railway, which is here 5,077 feet above the sea, or about 150 feet above the level reached by the artesian water in the north basin.

In the summer of 1908 a prospect hole for oil was put down about one-half mile east of Juab. It was 12 inches in diameter at the top and 6 inches at the bottom and reached a depth of 560 feet. Water was struck at different levels and when the drill reached a depth of 165 feet the water rose above the surface and overflowed at a rate estimated by the driller at about 200 gallons per minute. The drilling was finally stopped because of the abundance of water. The entire hole is said to penetrate valley deposits. The section to the depth of 353 feet is reported by the driller as follows:

Section of well east of Juab.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and gravel	30	30
Coarse gravel (water)	10	40
Blue clay	5	45
Quicksand and gravel (water)	75	120
Conglomerate	7	127
Yellow clay	3	130
Gravel, with layers of quicksand and clay (flow)	35	165
Conglomerate alternating with blue and yellow clay	188	353

In the center of the valley in both basins the sediments washed in from the mountains no doubt extend to considerable depths, and the lower portions probably include beds of gravel that contain water under fully as great pressure as the shallower beds that have hitherto provided the flows. Artesian water should not be expected on the

bench lands, but the amount of water recovered through flows in the low areas could be increased if wells of larger diameter and somewhat greater depth were drilled.

GROUND WATER BENEATH THE BENCHES.

In the two low central areas in which flows are obtained ground water is invariably found near the surface and springs are abundant. In passing from these central areas up the slopes toward the mountains, the ground water occurs at greater depths as the altitude increases. Where flows are not expected, the wells are usually dug by hand and are not sunk far below the level at which the first water is found. Though the yield of such wells is not large, it is generally sufficient for domestic and stock uses.

In the vicinity of York, at the north end of the valley, about a dozen wells have been sunk. Some of these wells found seeps at a depth of less than 30 feet; others were carried to depths of over 100 feet. (See fig. 9.) In the village of Mona the domestic supplies are derived chiefly from wells ranging in depth from a few feet to more than 100 feet, according to the altitude of the surface. At Nephi, which is located on the alluvial fan of Salt Creek, far above the low central area in which flows are obtained, there are at present no wells, but a successful well about 160 feet deep was at one time sunk. Farther down the slope, northwest, west, and southwest of the city, a number of wells have been dug, their depth depending on the altitude of the surface. On the west side of the north basin wells are scarce, but ground water in sufficient quantities for domestic and stock purposes can probably be obtained, especially under the lower parts of the slope.

A number of wells have been dug in the fields below Levan, and ground water could probably be found beneath the village at depths not greatly exceeding 100 feet. A few wells have also been sunk south of Levan and in the region northwest of Levan, to within 1¼ miles of Sharp station. At the Little Salt Creek settlement there are several wells about 50 to 100 feet deep. On the farm of the Juab Development Co., in sec. 19, T. 15 S., R. 1 W., just west of Chicken Creek reservoir and near the west margin of the valley, a well was drilled into rock and carried to a depth of 620 feet before obtaining a satisfactory yield. The water in this well rises to a level 22 feet below the surface.

Nearly all the wells in this valley are found within the areas in which the ground water is less than 100 feet below the surface (fig. 9), but recent dry-farming developments have created a demand for water supplies farther up the slopes, especially on the Levan Ridge. The ordinary failures of attempts to find water in the higher

areas are readily explained by the fact that sufficient account was not taken of the altitude, the holes having been abandoned before there was any reason for expecting water. It is probable that wells sunk some distance beyond the limits of existing wells will be successful if digging or drilling is carried to sufficient depths, but the upper parts of the slopes should of course be avoided.

The most southerly well in the north basin is located about 2½ miles north of Sharp Station and has water at a depth of about 60 feet. The most northerly well in the south basin is that of Grace Bros., in the NW. ¼ sec. 14, T. 14 S., R. 1 W., just west of the railway and about 1¼ miles southwest of Sharp (fig. 9). This well is 102 feet deep and its section is said to consist almost entirely of red clay, in which a seep was obtained at the depth of 92 feet. About 2 miles south of Sharp and at a somewhat lower level than the Grace Bros.' well, is the well of J. W. Paxman, which is 56 feet deep and yields generously. In the last two wells the water stands at a level of about 5,100 feet above the sea, or not much more than 100 feet below the surface at Sharp, which has an elevation of 5,224 feet. This station is situated at approximately the lowest point of the divide between the north and south basins, and eastward from it the surface rises at the rate of about 100 feet per mile for several miles, beyond which the grade becomes steeper. (See fig. 9.) These relations give a basis for forecasting the depth to the ground-water table beneath the Levan Ridge.

QUALITY OF WATER.

The ground water in Juab Valley is hard, but, as a rule, is otherwise of good quality, this being true even of wells and springs in close proximity to alkali soils. A few of the shallow wells, especially on the west side, are reported to yield somewhat saline water, but here water of better quality can probably be found by tapping a deeper bed. The quality of the water used at Starr as locomotive supply is shown by the following analysis. This water is derived from a flowing well about 100 feet deep.

Analysis of water from the railway well at Starr.

	Parts per million.
Total solids	267.5
Siliceous matter (SiO_2)	4.5
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	1
Calcium carbonate ($CaCO_3$)	112
Magnesium carbonate ($MgCO_3$)	52
Sodium chloride ($NaCl$)	23
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile, organic and loss	75

IRRIGATION WITH GROUND WATER.

Much of the water that sinks into the gravelly deposits in the upper parts of the slopes, reappears in the low wet areas along the central axis of the valley, where it goes to waste or is put to poor use. A large part of this surplus ground water could be recovered through wells before it reaches the central areas and could be applied to fertile soil that is now idle for lack of water.

Up to the present time irrigation with ground water has not been attempted except on a very small scale, chiefly from 2-inch flowing wells. Though more water could be obtained from flowing wells than is at present derived from this source, yet the possibilities of irrigating with artesian water are limited by the fact that much of the low land where copious flows can be obtained is too poorly drained and contains too much alkali to be successfully cultivated. If wells were drilled on somewhat higher ground and pumps were installed, water could be recovered in larger quantities and applied to better land. Before pumping plants are installed the precautions discussed on pages 49–53 should be taken. Pumping plants could probably be best employed in providing supplementary supplies for the latter part of the growing season, when the flow of the streams diminishes.

CULINARY SUPPLIES.

At Nephi water for domestic uses is derived from springs and led to the city through a gravity pipe line. At Levan the stream water that flows through the village is used. At Mona and most of the smaller settlements and isolated ranches the drinking and culinary supplies are obtained from wells. For some of the dry farms water is hauled from distant sources.

ROUND, LITTLE, SAGE, DOG, AND FERNOW VALLEYS.

TOPOGRAPHY.

The mountainous region west of Juab and Sevier valleys embraces a north-south trough in which lie several small valleys that contain tracts of arable land. West of this trough are the East Tintic, Canyon, and Pavant ranges, which form the highest part of the mountainous region; east of the trough is a group of lower ridges, the southern part of which is known as the Valley Range. Sevier River breaks into this trough through a gap in the east rim, flows northward for about 10 miles in what is locally known as Little Valley, and then escapes into Sevier Desert through a deep canyon cut into

the lofty west wall. Before the river leaves Little Valley it is joined by the channel of Chicken Creek, which enters from the south basin of Juab Valley through another gap in the east rim. Farther north a rock-ribbed region, including Sage, Dog, and Fernow valleys, and a small part of East Tintic Valley, is drained, at least potentially, into this section of Sevier River. At the south end of the trough lie Upper and Lower Round valleys. (See Pl. I.)

GEOLOGY.

The oldest rocks in this region consist of indurated Paleozoic quartzites and limestones which have been folded and greatly eroded. They lie at the surface in many localities, chiefly in the northern part of the region, and form the core of the Canyon and Pavant ranges. Younger strata, consisting mainly of red and buff conglomerates, sandstones, and shales, rest upon the irregular erosion surface of the quartzites and limestones, producing a pronounced unconformity, which is well displayed on the east flank of the Canyon Range. These younger strata are believed to be, at least in part, of early Tertiary age. They do not occur at the north end of the region, but they form the east wall of Sage Valley and become increasingly prominent south of Sevier River until, in the Round Valley area, they conceal the older formations almost entirely. They are less folded than the Paleozoic strata but are fractured and faulted and in this region they generally dip toward the east. In Fernow and Dog valleys the Paleozoic formations are partly covered by volcanic rocks, which are probably younger than the Tertiary sediments.[1]

RAINFALL.

The following table presents a record of the monthly precipitation at Scipio, in Round Valley, where observations have been made for the United States Weather Bureau since 1894. The average annual precipitation at this point is somewhat less than at Levan, about the same as at Fillmore, and decidedly more than in the desert region farther west. (See p. 19 and fig. 3.) Approximately 35 per cent of the precipitation occurs in the spring, 14 per cent in the summer, 24 per cent in the fall, and 27 per cent in the winter. (See fig. 4.) Dry farming has been undertaken on a large scale in Dog and Little valleys, the principal crop being winter wheat.

[1] Smith, G. O., Tintic special folio (No. 65, Geol. Atlas U. S., U. S. Geol. Survey, 1900, p. 2.

Precipitation (in inches) at Scipio.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1894	.....	.....	.....	.....	.....	.....	.68	1.53	2.08	.....	.00	2.00	.....
1895	.58	.....	2.12	.....	.....	.33	.42	.28	.38	.83	1.35	.80	.....
1896	1.22	.10	1.51	1.06	1.36	Tr.	2.82	1.59	.89	1.53	1.14	.40	13.62
1897	2.60	2.61	3.26	1.26	.73	.21	.42	.38	1.39	3.34	1.55	1.49	19.24
1898	1.89	1.62	3.41	.35	2.83	1.10	.19	.44	.00	.....	1.36	1.10	.....
1899	1.40	2.28	3.85	.51	.70	.43	.58	1.03	.00	2.06	.83	1.85	15.52
1900	1.04	.20	.10	2.09	.01	.10	Tr.	.37	1.17	.57	1.17	.10	6.92
1901	.60	2.43	1.02	1.07	.83	.27	1.12	2.67	.10	1.31	.51	.76	12.69
1902	.80	1.61	2.25	1.17	.84	.08	.07	.21	1.38	.56	2.31	.47	11.75
1903	1.51	.86	1.59	1.83	1.96	.36	.27	.17	.98	.67	.48	.33	11.01
1904	.82	1.74	3.21	.27	2.01	.28	.50	.51	.30	.95	.00	1.99	12.58
1905	.67	4.70	2.58	2.00	3.08	.09	.43	1.01	2.88	.53	2.66	.50	21.13
1906	1.73	1.08	3.97	3.07	2.12	.71	.46	1.64	1.68	.17	1.99	1.44	19.99
1907	2.39	2.35	1.41	1.19	1.80	1.22	.67	2.17	.73	1.35	.28	2.67	18.03
1908	.16	1.09	.94	.46	3.56	.68	.98	1.48	2.09	3.33	.46	.74	15.97
Average	1.24	1.74	2.23	1.26	1.68	.42	.64	1.03	1.21	1.32	1.07	1.10	14.87

WATER SUPPLIES.

ROUND VALLEY.

At the south end of the mountainous trough lies Upper Round Valley, which is hemmed in on the east and south by the Valley Range and on the west by the precipitous up-faulted wall of the Pavant Range, but which opens northward into Lower Round Valley. The lower valley, in which is located the village of Scipio, is bounded on the east by the Valley Range, on the west by the Pavant and Canyon ranges, and on the north by a low ridge, through which has been cut a gap that is no longer functional as an outlet for the drainage.

The water supply comes from a series of large springs and spring-fed streams near the head of the upper valley, the principal sources being Maple Grove Spring, Rock Creek, Phoero Creek, and Willow Creek. (See Pl. I.) The water flows to a depression near the outlet of the upper valley, where a reservoir has been constructed, and is thence allowed to flow to the lower valley, where it is used by the people of Scipio for irrigation. Any surplus water collects in the lowest part of the valley. Faintly outlined strands show that at some time in the past the lower valley held a lakelet with an area of several square miles. North of the pass to Holden there are several canyons that contain springs and small intermittent streams, but their discharge is not large enough nor regular enough to be of much value for irrigation.

The upper and the lower valley each constitutes a relatively independent rock basin containing a rather thick deposit of loose sediments that are partly saturated with water. In the lower valley there are many wells, most of which are in or near Scipio, where they furnish the greater part of the supply for drinking, household, and

stock use. The ground-water level fluctuates with the rainfall and the amount of irrigation water that is used. In the southeastern part of Scipio the depth to water is more than 100 feet, but on the lower ground in the northwestern part of the village and in the adjacent area to the west it is generally less than 10 feet. Two test wells have been sunk in the hope of obtaining flows. One was drilled in the village square and is said to have been carried to a depth of over 300 feet, apparently all in loose valley deposits. The other was drilled near the residence of H. Esklund, one-half mile or more west of the square and at a lower altitude. In both wells the water from the deeper beds rose fully to the level of the superficial ground-water table, but in neither was a flow obtained. In the shallow-water belt ground water could probably be profitably pumped for irrigation. In the southeastern part of the village, where water from the irrigation ditches is used for household purposes, more satisfactory supplies could be obtained by sinking wells.

LITTLE VALLEY.

Little Valley may be said to constitute the valley of Sevier River from the Sevier Bridge dam to the point where it enters the canyon in the Canyon Range. (See Pl. I.)

In the level reach above the canyon the river has only a slight grade and is bordered by swampy bottom lands on which a dozen or more flowing wells have been drilled. (See Pl. I.) They are located on sections 15, 21, 22, 23, 27, 28, and 34, in T. 15 S., R. 2 W. Most of them are 2 inches in diameter and pass through clay, sand, and gravel to depths of a little over 50 feet. The water rises only a few feet above the level of the river and the yield is generally less than 10 gallons a minute. The land on which the flows are obtained lies so low that it is not possible to make much use of the water for irrigation. Several springs of good size also occur near the river.

On the east side of the valley, a short distance south of Chicken Creek, a well 2 inches in diameter and 320 feet deep was drilled for the Juab Development Co. It is said to end in valley sediments without reaching rock, and the water rises within 18 feet of the surface or slightly above the river level. This well is frequently pumped continuously for several hours at the rate of 5 gallons per minute.

The west side of the valley is occupied by a broad upland belt which is underlain in part by Tertiary strata that are dissected into a sort of bad-land topography and in part by younger sediments. In the lower portions of this belt, lying near the river, there will probably be no difficulty in obtaining enough water for domestic and stock use by sinking to moderate depths in the valley sediments, but on the higher levels the prospects are not good.

SAGE VALLEY.

Sage Valley lies north of Little Valley and its surface rises gradually from Sevier River to the rocky ridges that separate it from Dog Valley. (See Pl. I.) As far as was ascertained, it contains no spring, stream, or well. Wells sunk near the south end, where the surface is low and the valley sediments are generally deep, would doubtless obtain water, but farther north these sediments are likely to be drained and drilling would be an uncertain undertaking.

DOG AND FERNOW VALLEYS.

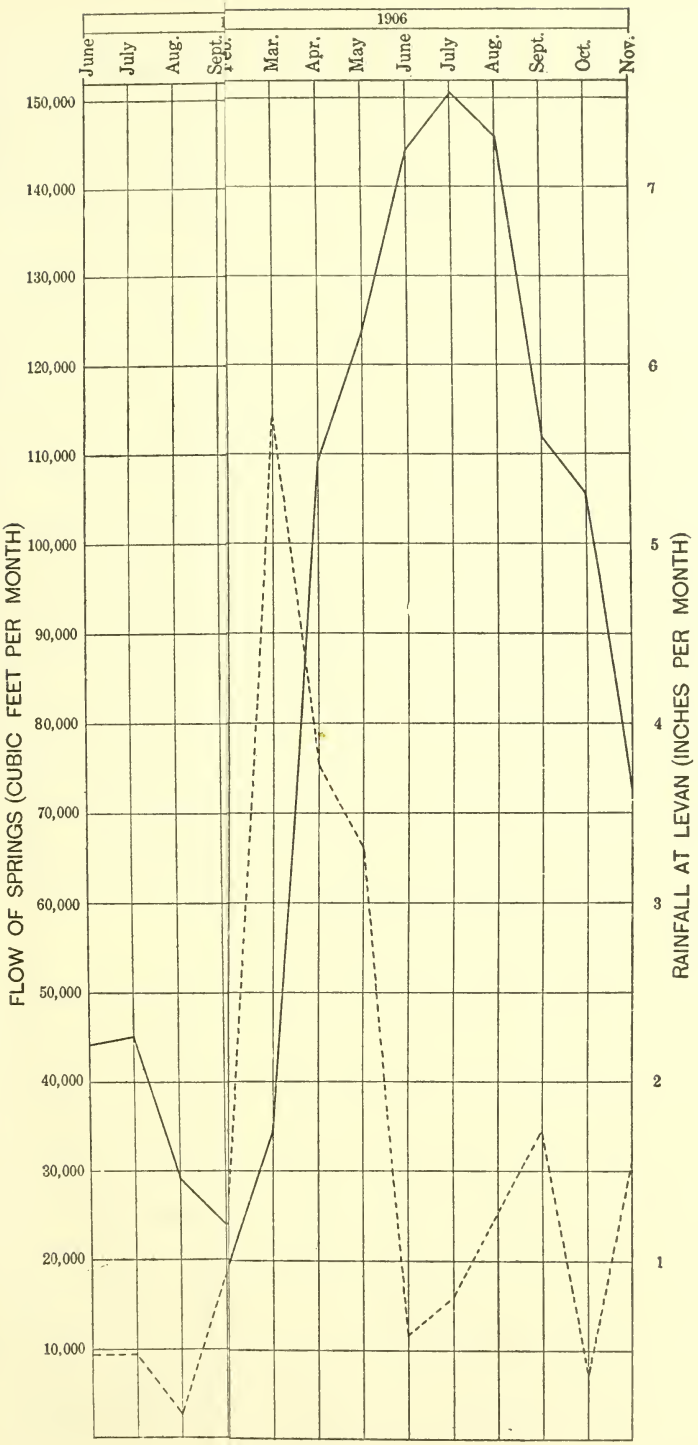
Dog and Fernow valleys lie several hundred feet above Juab Valley and Sevier River, and are hemmed in on all sides by rocky walls consisting of Paleozoic limestones and quartzites and Tertiary igneous rocks. The rock of both valley floors are in most places covered with loose sediments, but irregularities of the surface as well as exposures of the bed rock in certain localities indicate that the average thickness of these sediments is not great. Both valleys have gorge-like outlets toward the south, but neither has any permanent stream. At the north end of Fernow Valley several small permanent springs issue from the porous mantle of disintegrated material that covers the impervious igneous rocks at the head of the valley. Recently a pipe line about 5 miles long has been laid from one of these springs to the headquarters of the Utah Arid farm, in Dog Valley.

There is no well in either valley, but two unsuccessful attempts to obtain ground water have been made in Dog Valley—the first, a dug hole about 75 feet deep, in which no water was found; the second, a drilled hole put down in 1908 by the State of Utah. At a depth of 230 feet in the drilled hole no water had been found, but some sort of hard rock was encountered and the project was abandoned. There are no surface indications that the unconsolidated sediments contain water. The underlying limestones are likely to be traversed by fissures or solution passages which may allow the storm water that seeps into the unconsolidated sediments to escape to lower levels.

TINTIC VALLEY.

GENERAL FEATURES.

Tintic Valley extends for nearly 30 miles in a north-south direction and comprises more than 300 square miles (Pl. I). It is walled in on the east and northeast by the East Tintic Mountains, on the southeast by the Canyon Range, and on the west by the West Tintic and Champlin mountains, its outlet being toward the south through a constricted portion of the valley.



TO PRECIPITATION.

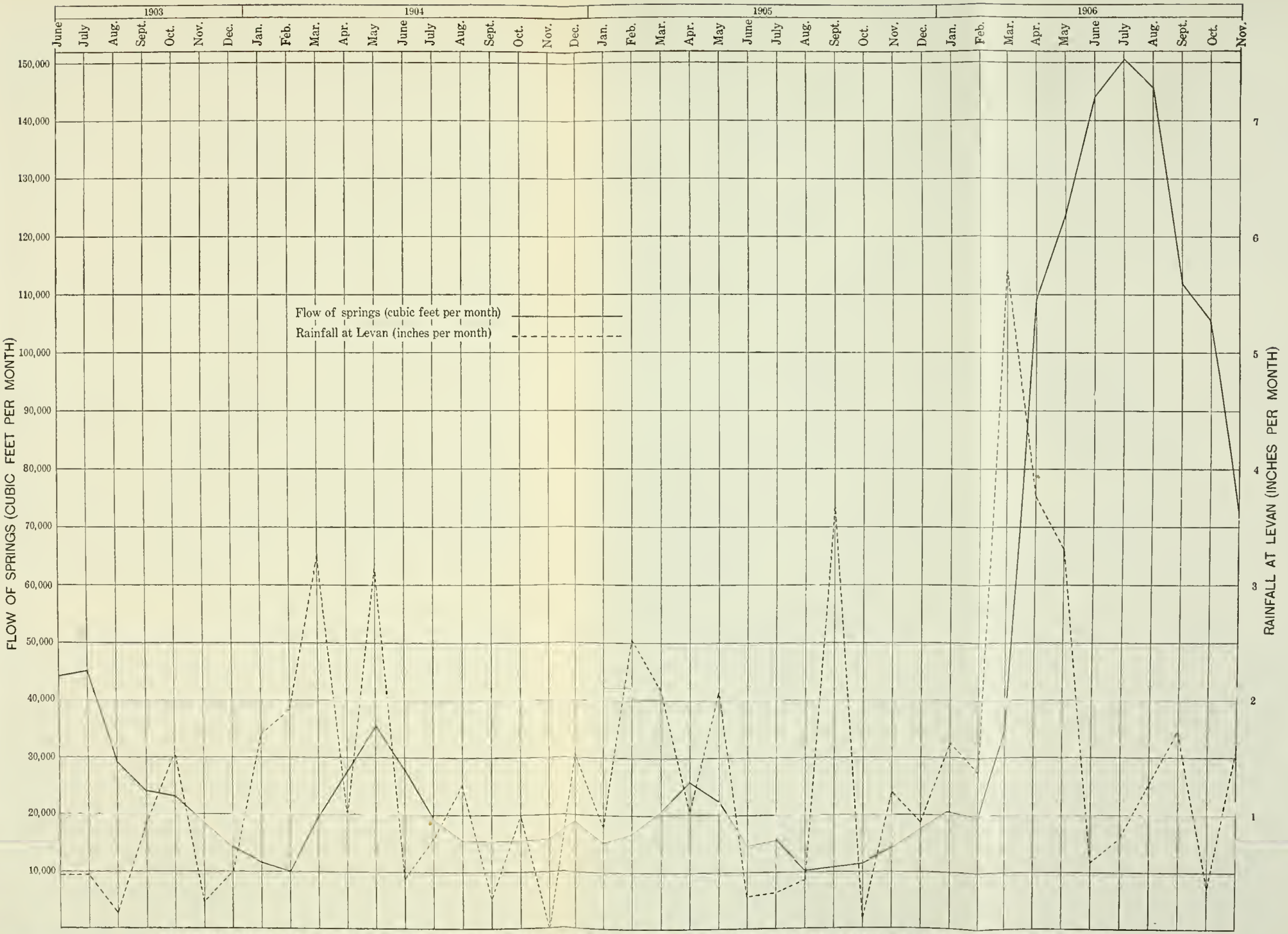


DIAGRAM SHOWING FLOW OF THE SPRINGS THAT SUPPLY SILVER CITY AND THE RELATION OF FLOW TO PRECIPITATION.

The stream channel which marks the central axis descends from about 6,000 feet above sea level, near the north end, to 4,900 feet where it enters the Sevier delta region, 200 feet above Sevier River. The alluvial slopes that extend from the mountain borders to the center of the valley are steep and gravelly, and are dissected to an unusual degree, the erosion topography in many places giving a relief of over 100 feet. The central draw is depressed below the adjoining bench lands out of which it has been excavated, and south of Jericho it expands to form the flat bed of ancient Lake Bonneville, bordered by terraces of the Bonneville stage. The draws or stream valleys that are cut into the unconsolidated sediments are probably chiefly relics of the humid epoch when Lake Bonneville existed.

Cedars and large sagebrush are found on the upper parts of the slopes, and rabbit brush grows in the draws, that collect some moisture. On the old lake bed the vegetation is dwarfed and scanty. No rainfall observations are available for this region, but the character of the vegetation seems to indicate less intense aridity than in the region farther west. The high bench land is gravelly and the low draws and lake bed show indications of alkali, but areas of what appears to be good soil are found at intermediate levels.

The San Pedro, Los Angeles & Salt Lake Railroad enters the region through Boulter Pass at the north end, extends southward through the entire length of the valley, and makes its exit through the outlet at the south end. Except for the people at the McIntyre ranch, in the heart of the valley, and a few railroad employees the valley is virtually destitute of permanent inhabitants. Dry farming has not been seriously attempted.

WATER RESOURCES.

In the mountains at the head and sides of the valley springs are numerous, but they are widely scattered and are not of sufficient size to be of much value for irrigation nor to give rise to streams of any importance. Consequently the broad alluvial slopes are destitute of water except on rare occasions when the snow melts or a rainstorm occurs and a mud-laden flood courses down the arroyos. The only partial exception to this condition is the valley of Cataract, or Death, Creek, which heads in the highest part of the West Tintic Mountains and leads southeastward toward McIntyre and which in some seasons contains a small stream.

Although little prospecting has been done, there is evidence that water exists in the valley deposits and that the central draw along a part of its course has been eroded to the ground-water level.

In the vicinity of the McIntyre ranch, which is near the station of McIntyre, sec. 28 (?), T. 11 S., R. 3 W., near the junction of the

main Tintic draw with the draw of Death Creek, the flat-bottomed and deeply intrenched stream valleys receive numerous seeps and small springs that make it possible to raise a little grass and grain. At the old smelter, a short distance north of the ranch house, ground water was at one time tapped by running tunnels to distances of several hundred feet beneath the benches adjoining the valley, and water still flows from these abandoned tunnels. At this point there is also a shallow open well and a 2-inch flowing well, which is about 90 feet deep and usually yields several gallons per minute, though it is known to have stopped flowing in summer. At the ranch house there is a flowing well, said to be 190 feet deep, which yields a small supply of water. (See Pl. I.)

About midway between McIntyre and Jericho stations, in ravines on the east side of the railway, are several small springs, variously known as Cazier Spring, Squaw Bush Spring, Twin Springs, etc. (Pl. I), which, together with the Riley Springs in the mountains, furnish the railway supply at Jericho, the water being led to this station through pipe lines by gravity.

In the valley, a few miles south or southwest of Jericho, several wells have, at different times, been dug to depths of 50 to 100 feet, and fairly good supplies of water have been found.

About 2 miles north of McIntyre station, in a draw on the east side of the railway, there was at one time a well about 60 feet deep, which is said to have had good water and to have been pumped by a windmill.

About 1½ miles northwest of Tintic Junction, a short distance west of the railway, and situated on dissected bench land, is a dug well belonging to G. A. Franke, which is 165 feet deep and contains about 12 feet of somewhat mineralized water. In a ravine southwest of the Franke well, and a short distance north of the Cherry Creek pipe line, is another dug well, which is said to have found good water at a depth of about 50 feet.

The steep, gravelly character of the alluvial slopes makes it probable that beds of sand and gravel extend to the center of the valley, and the springs and wells that have been described give reason to believe that these porous beds are saturated below a certain level and that wells sunk to moderate depths in the lower parts of the valley will be successful; but as the ground water is not under sufficient head to rise to the level of the more fertile land, little irrigation will probably be possible from flowing wells. On the higher ground in the peripheral parts of the valley the depth to water is in all probability too great to make its recovery practicable.

In most places the limestone and quartzite formations of this region dip away from the valley, and other conditions are unfavorable for obtaining water by drilling into rock.

QUALITY OF THE WATER.

The water from most of the wells and springs in this valley is of fairly good quality and is considered satisfactory for drinking and for culinary uses. The result of an analysis, made in September, 1903, of the water from Cazier Spring, which is used by the railroad company for locomotive supplies, is presented in the following table:

Analysis of water from Cazier Spring, in Tintic Valley.

[Parts per million.[1] Analyst, Herman Harms.]

Total solids	508
Siliceous matter (SiO_2)	57
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	3.5
Calcium carbonate ($CaCO_3$)	137
Calcium sulphate ($CaSO_4$)	38
Magnesium carbonate ($MgCO_3$)	39
Sodium chloride ($NaCl$)	163
Calcium chloride ($CaCl$)	Trace.
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile, organic, and loss	70

TINTIC MINING DISTRICT.

GEOLOGY.

The Tintic mining district, one of the oldest and most productive in the State, is located near the north end of the East Tintic Mountains. The geology of the region has been described in detail by George Otis Smith.[2]

The indurated rocks belong to two distinct groups: A thick stratified series, consisting chiefly of Paleozoic limestones and quartzites, and a series of igneous rocks of Tertiary age. After the stratified rocks had been compressed into large folds and had been somewhat fractured and faulted they were extensively eroded. Later they were invaded and in large part covered by the Tertiary lavas, which, in their turn, have also been submitted to prolonged weathering and erosion. The two systems differ radically in their relations to ground water.

WATER IN LIMESTONE AND QUARTZITE.

The areas underlain by the Paleozoic stratified rocks are practically destitute of springs and wells (fig. 10) and the rocks themselves are barren of water to great depths, several of the mines in this region having been sunk to low levels without finding water or passing beneath the zone of oxidation. According to reports, the Eureka

[1] Originally reported in grains per gallon.
[2] Tintic special folio (No. 65), Geol. Atlas U. S., U. S. Geol. Survey, 1900.

Hill mine has reached a depth of 1,500 feet (4,976 feet above sea level), the Centennial mine a depth of 1,800 feet (5,093 feet above sea level), and the Mammoth mine a depth of 2,260 feet (4,780 feet above sea level), each without finding water, while in the Gemini mine water is reported at the 1,600-foot level (4,867 feet above the sea), and a pump is operated at the rate of about 100 gallons per minute. Apparently such fractures as exist in the limestone allow the water to descend to profound depths.

WATER IN IGNEOUS ROCKS AND OVERLYING WASTE.

SPRINGS.

As is shown in figure 10, numerous springs are found in those parts of the mountains where igneous rock constitutes the surface formation. The rock itself is nearly impervious, but its upper portion has been disintegrated into loose, porous, gritty materials, with which it is covered in localities that are sheltered from active erosion. The rain percolates into the débris mantle, but is prevented from descending far because of the underlying unweathered rock. Accordingly, the ground water either accumulates or seeps along the surface of the firm rock until it reaches a point where the rock crops out and the water is returned to the surface in the form of a spring or seep.

Most of these springs are small, and as they are fed from shallow sources their flow varies greatly. In figure 10 the yield of a group of springs, whose water is led through a pipe line to Silver City, is plotted for a period of three and one-half years, during which their flow was measured, and on the same diagram is shown the precipitation for this period at Levan, one of the nearest points at which rainfall observations were made. The diagram shows that the yield fluctuates widely and that the fluctuations follow those of the rainfall with but slight lag. This diagram should not be given too strict an interpretation because the rainfall in the vicinity of the springs may have had a somewhat different distribution than at Levan and also because of repairs that were made on the system and meter within this period. Nevertheless, the records for this region show conclusively that the heaviest rainfall occurs in the spring months, and these spring rains no doubt account for the increase in flow shown in this season each year. Moreover, the radical increase in flow in 1906 is clearly the result of an abnormal amount of precipitation at that time, for the records of the 11 stations for which data are given in this report all show more than the average amount of rainfall during this year, and 9 show more rainfall during this year than during any other in which records were kept.

Springs of this type furnish supplies for Silver City, Jericho, and the Utah Arid farm, in Dog Valley.

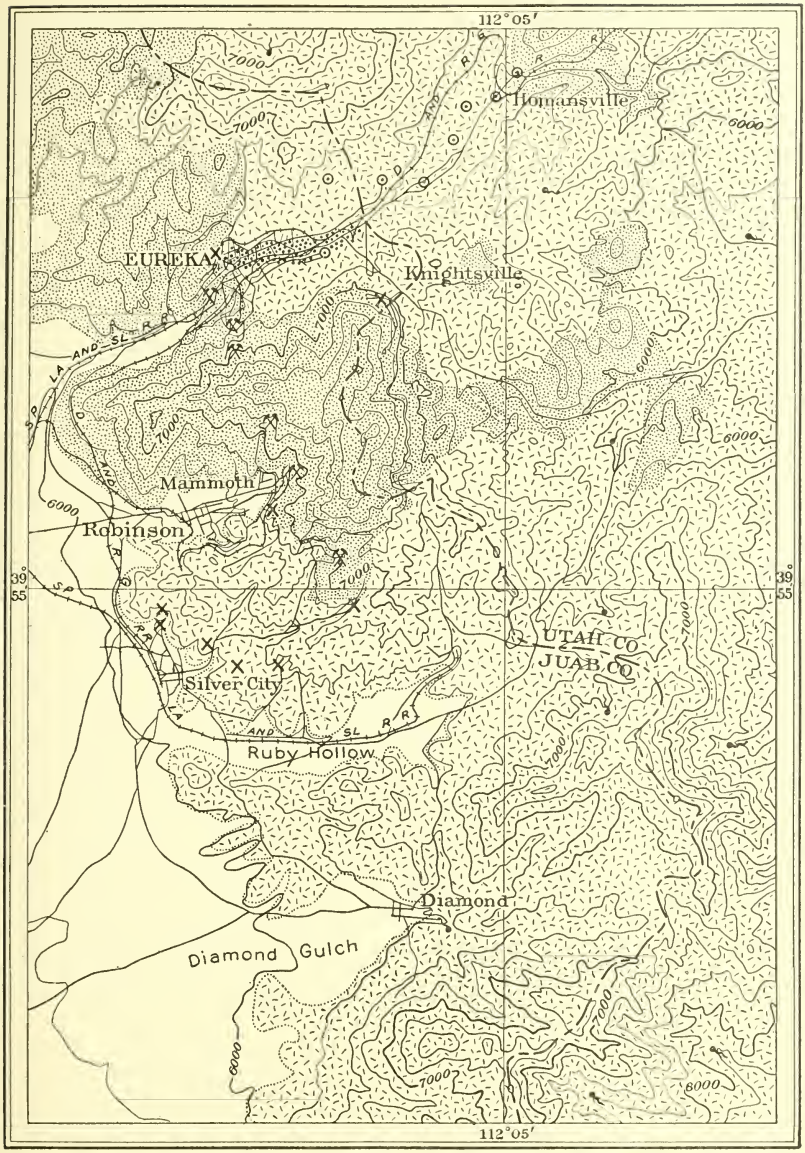


FIGURE 10.—Map of Tintic mining district, showing the relation of the water supply to the igneous rocks. (Geology after George Otis Smith, Tintic special folio.)

WELLS.

Valuable supplies of water are derived from wells and infiltration galleries in the sediments overlying the igneous rocks and in the partly disintegrated upper portion of the rocks themselves. These wells are situated in the Eureka and Homansville gulches, which are on opposite sides of the main divide. (See fig. 10, p. 83.) The upper part of each of these valleys is underlain by igneous rocks, is relatively broad and open, and is mantled with residual waste and sediments carried down from the mountain sides; but farther down in each valley the igneous rocks give way to the more resistant limestones and quartzites, and the valleys accordingly become more constricted and canyon-like. The wells are found in the upper parts of the valleys, as shown in figure 10.

In Eureka there are many private wells that are dug to depths ranging from about 15 to 125 feet. Most of these wells extend to the hard rock or are sunk a short distance into the rock, and they derive their meager supplies from seepage near the bottom of the loose materials. Near the divide and in the Homansville Basin greater quantities of water are recovered through large vertical shafts and horizontal tunnels that afford extensive infiltration surfaces. Two of these plants may be considered typical.

The water for the Gemini pumping station in the Homansville Basin is obtained from one or more shafts which are 60 feet deep and end in partly decomposed rock, and from two tunnels at the 60-foot level, which are about 5 by 7 feet in cross section and have a combined length of about 900 feet. At the time the plant was visited the water level was only 20 feet below the surface, but it is reported to descend nearly to the bottom in dry seasons. The pump is operated about 14 hours each day at the rate of 27 gallons per minute, and the engineer in charge estimated that the maximum yield for continuous pumping is only about 25 gallons per minute. The water is considered satisfactory for use in boilers.

At the Eureka Hill pumping plant, situated a little farther northeast in the same basin, there is a main shaft, about 4 by 6 feet in cross section, that extends to a depth of 265 feet, largely through incoherent materials consisting of clay, bowlders, and sand; two other shafts; and tunnels at the 65-foot and lower levels, said to aggregate several thousand feet in total length. At the time the plant was visited it was reported that the normal water level was 20 feet below the surface but that the water in the well was drawn down to 60 feet below the surface by pumping. The pump is operated at the rate of about 80 gallons per minute for about 5 to 12 hours each day, fully 50,000 gallons being withdrawn on certain days. The water is only moderately mineralized but varies considerably in mineral con-

tent, probably with changes in the water level. The following table presents two analyses of this water made by the Dearborn Drug & Chemical Co.:

Analyses of Homansville well water.[1]

[Parts per million.]

	August, 1895.	June, 1897.
Total solids	400	320
Silica (SiO_2)	60	48
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	9.9	1.2
Calcium (Ca)	44	55
Magnesium (Mg)	29	26
Sodium and potassium (Na+K)	65	33
Bicarbonate radicle (HCO_3)	163	146
Sulphate radicle (SO_4)	65	35
Chlorine (Cl)	48	49

[1] These analyses were originally given in hypothetical combinations and in grains per gallon. All of the carbonates have been recalculated as bicarbonates.

The Homansville wells furnish good illustrations of the fact that, if the filtration surfaces are made sufficiently extensive, important quantities of water can be recovered from materials whose specific yield is very small.

MINES.

Near Silver City there are many old mines that have been developed entirely in igneous rocks. They have invariably encountered water that descends along the veins or fracture zones but does not seem to have free means of escape into the subjacent limestone. As the water in the different veins is not in close communication, the level at which it occurs differs radically within short distances. Although the quantity of water is sufficient to be troublesome in mining operations, it is not great when compared with the dimensions of the underground workings. Mines that have been developed in igneous rocks representing lava flows generally lose their water by downward percolation when they are sunk into underlying limestone.

DOMESTIC AND INDUSTRIAL SUPPLIES.

To obtain enough water for domestic and industrial supplies the meager sources of this area have been heavily drawn upon and one source entirely extraneous to the area has been called into requisition.

The large wells in the Homansville Basin and in the upper part of Eureka supply a number of the principal mines, the Rio Grande Western Railroad, and much of the water for domestic consumption in Eureka, and small private wells in the city are also used for domestic purposes. The water from springs whose flow has already been discussed is conducted through a pipe line, by gravity, to this region, where it supplies the domestic consumption of Silver City and also a smelter and several mines.

On the west flank of the West Tintic Mountains, about 20 miles from Mammoth, there is a pumping plant that lifts water from Cherry Creek to the summit of the range. From the summit the water is conducted, through a pipe line, across Tintic Valley to Robinson, where a second pumping plant is used in raising a part of the water to the higher levels of Mammoth and some of the mines. It is estimated that about 150,000 gallons are pumped daily at Cherry Creek. The water thus obtained provides the railway supply at Tintic Junction, the domestic supplies at Robinson and Mammoth, and the supplies for several of the mines. The water is reported to be somewhat hard but otherwise of good quality.

PAVANT VALLEY.

TOPOGRAPHY.

The Pavant Range extends along the southeastern border of Millard County and forms a continuous mountain tract nearly 50 miles long, with its highest peaks rising 5,000 feet above the adjacent country, or 10,000 feet above the sea (Pl. I). It abounds in springs and streams and supports a forest of large trees. In ground plan the range is a crescent, one horn of which projects north and the other southwest. On its southeastern convex side is the valley of Sevier River, which follows a course roughly concentric with the crest of the range. In the concavity on the opposite side, this range shelters the agricultural settlements of Kanosh, Hatton, Meadow, Fillmore, and Holden, beyond which stretches the sterile desert of western Utah. Toward the north the range bifurcates into the main Pavant Range and the Valley Range, and between these two forks lies Round Valley. North of the pass to Scipio the Canyon Range constitutes a virtual continuation of the Pavant Range.

From the north end of Pavant Valley to beyond Kanosh extends a relatively smooth and featureless, yet somewhat dissected, alluvial slope, which descends gradually from the mountain borders and passes insensibly into the flat bottom lands. Its broad and even expanse is interrupted north of Fillmore by "Cedar Mountain" and "Bald Mountain," and west of Kanosh by two lava buttes. (See fig. 11.) When Lake Bonneville stood at its highest level this slope was partly submerged, and at the water's edge a shore line was cut that can be seen distinctly when the region is viewed from the west. This shore line lies between the 5,000-foot and 5,500-foot contours as shown on the map (fig. 11). It passes through Holden and Fillmore and a short distance back of Meadow and Kanosh. On the west the bottom lands are to a large extent hemmed in by various low mesas of volcanic origin, but to the northwest, between the

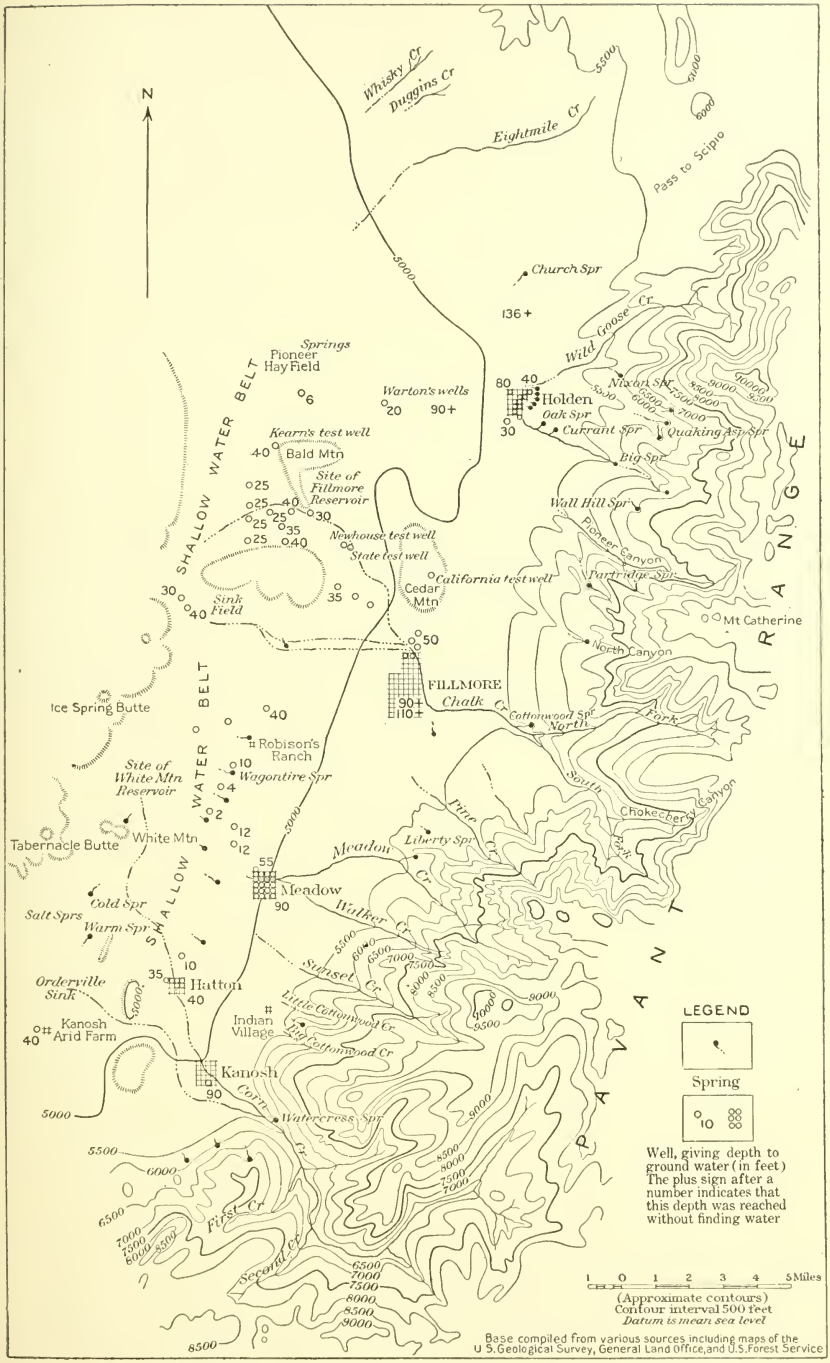


FIGURE 11.—Map of Pavant Valley, showing streams, springs, and ground-water conditions.

Canyon Range and Pavant Butte, they merge into the level expanse of Sevier Desert.

GEOLOGY.

The rocks of this area include (1) quartzites and limestones, (2) conglomerates, sandstones and shales; (3) volcanic and intrusive rocks; and (4) unconsolidated stream and lake sediments. In age, the first are Paleozoic, the second Mesozoic and Tertiary, the third Tertiary, Pleistocene, and Recent, and the fourth chiefly late Tertiary and Pleistocene. The limestones and quartzites form the core of the Pavant Range from the north end to the westward projection southwest of Kanosh, and they are also exposed in ridges in the valley between Fillmore and Holden. After they had been deformed and eroded they were covered by the deposits that hardened into conglomerates, sandstones and shales, and that were later deformed and deeply eroded. At the south end of the range and in the mountains still farther south igneous rocks of Tertiary age occur in great quantity. In the desert to the west lavas and tuffs, ranging in age from Tertiary to very recent, lie at the surface in many localities, forming a chain of buttes and low mesas that partly isolate Pavant Valley from the main desert. Prominent among these buttes are Pavant Butte (locally known as Sugar-Loaf Mountain), Ice Spring Buttes, and Tabernacle Butte, all of which have been described in detail by G. K. Gilbert in his monograph on Lake Bonneville.

RAINFALL.

Observations made at Fillmore for the United States Weather Bureau show that during a period of 17 years the annual precipitation has ranged from 9.32 inches (in 1900) to 21.28 inches (in 1906) (fig. 3), and has averaged 14.61 inches, of which 39 per cent has fallen in the spring months, but only 14 per cent in the summer months (fig. 4). The average precipitation is about the same as at Scipio and slightly less than at Levan, but nearly twice as great as at Deseret and Black Rock in the desert to the west. This difference in climate is reflected in the natural vegetation, for on the Pavant bench, as in Juab and Round valleys, large sagebrush flourishes, but farther west the brush has a more pronounced desert aspect. The Pavant Range, with its numerous streams and springs and its large timber, forms a striking contrast to the dry and barren Basin ranges.

Dry farming has been undertaken on a large scale west of Kanosh and on a smaller scale in other parts of the area, but at the time the region was visited (1908) it was uncertain whether this new enterprise would be successful.

Precipitation (in inches) at Fillmore.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1892	.....	.....	.....	2.11	2.03	0.82	0.29	0.47	0.06	1.07	0.53	1.20	.....
1893	0.81	1.51	2.89	2.09	1.53	.00	.48	1.71	1.21	.46	1.11	1.79	15.59
1894	.70	.56	1.04	2.43	.64	2.04	.34	1.19	1.94	.41	.31	1.77	13.37
1895	1.93	2.15	2.06	1.23	1.51	.80	.56	.97	1.66	.93	1.46	1.10	16.36
1896	.75	.16	.94	1.47	1.06	.01	2.36	1.69	.85	.37	1.17	.33	11.16
1897	2.15	2.17	2.89	1.26	.03	.26	.19	.31	1.50	3.59	1.15	1.55	17.04
1898	.15	1.20	3.07	.59	4.44	.96	.99	.06	Tr.	.60	1.27	.76	14.59
1899	.50	1.40	5.00	1.45	.85	.96	.01	.28	.00	1.94	1.06	1.03	14.48
1900	1.25	.45	.15	3.18	.35	.60	Tr.	.14	1.58	.93	.66	.03	9.32
1901	.35	2.00	1.54	2.35	1.92	.57	.41	.90	.00	.72	.15	1.97	12.88
1902	1.03	1.03	2.59	.36	.90	.09	.49	.16	1.51	.58	2.70	.46	11.90
1903	1.44	1.26	1.19	2.66	2.27	.04	.27	.38	1.00	1.06	.00	.40	11.97
1904	1.89	1.90	2.16	.26	2.81	.25	.07	1.13	.10	.62	.00	.95	12.14
1905	.90	2.48	2.66	1.53	2.45	Tr.	.53	.62	2.81	.51	1.13	.54	16.16
1906	.72	1.16	3.88	4.38	2.18	.40	1.27	1.20	2.38	.15	2.93	.63	21.28
1907	1.67	1.96	1.34	.55	3.20	.88	.97	1.23	1.24	1.99	.25	1.86	17.14
1908	1.01	.87	.36	.50	4.15	1.13	1.46	1.38	2.02	3.31	.69	1.55	18.43
Average	1.15	1.39	2.11	1.67	1.90	.58	.63	.81	1.17	1.13	.98	1.05	14.61

STREAMS AND MOUNTAIN SPRINGS.

The settlements at the west base of the Pavant Range are devoted almost exclusively to agriculture by means of irrigation, the water being derived, not from a single large source, but from a number of small streams that issue from the canyons and from numerous springs. (See fig. 11.) In general the flow of the streams is most copious in the spring when the snow in the mountains melts, but the discharge of any stream is likely to be temporarily greatly increased at any season by a heavy rainstorm in its small drainage basin. The normal flow is all carefully appropriated during the growing season, but as there are no reservoirs large amounts of water in times of flood and much of the winter flow passes the cultivated fields and reaches the bottom lands, where it is lost or produces a small amount of wild grass.

The largest streams are Corn Creek, which drains about 90 square miles and forms the principal irrigation supply for Kanosh and Hatton, and Chalk Creek, which drains scarcely 50 square miles but furnishes the main supply for Fillmore. At Meadow several small streams are relied upon (chiefly Meadow Creek, Walker Creek, and Sunset Creek), and at Holden several small streams (chiefly Wild Goose Creek and Pioneer Creek) and a number of large springs are utilized. A small amount of water issuing from the southwest flank of the Canyon Range is also used for irrigation.

SHALLOW-WATER BELT.

Between the alluvial slope on the east and the lava fields on the west there is a belt of low level land in which the ground-water table is nearly at the surface. (See fig. 11.) Here there are many springs and seeps, and wells obtain water at only slight depths. Both the

northern section of this belt, which lies west of Holden and is in part known as the Pioneer Hay Field, and the southern section, which lies west of Fillmore and Meadow, support a growth of grass without artificial irrigation and furnish rather extensive hay fields and pastures. A chain of fresh-water springs, shown in figure 11, occurs along the east margin of this belt from west of Fillmore nearly to Hatton. Several miles northwest of Hatton, near the northeast corner of sec. 24, T. 22 S., R. 6 W., is the Warm Spring, from whose tuffaceous basin flows a copious stream of mineralized water with a temperature of 94° F. Several cold springs yielding mineralized water occur farther west and north in this locality.

Most of the water in the shallow-water belt is derived from the mountains east of this valley, but some seepage no doubt also comes from the table-lands to the west and from the sandy tracts. In addition to the supply from these underground sources the surface waters that are not diverted for irrigation accumulate in the low areas. The contributions from surface sources are greatest in the winter and early spring, but those from underground sources reach their maximum at a later season. The water level is usually highest and the yield of the springs greatest in the summer, following with some lag the thawing of the snow and the heavy rainfall of the spring months.

ARTESIAN PROSPECTS.

Considerable attention has been directed toward the possibility of obtaining flowing water and several unsuccessful test wells have been drilled. One of these was sunk by the State of Utah, about 5 miles northwest of Fillmore (NW. ¼ sec. 36, T. 20 S., R. 5 W.), on low ground a short distance west of "Cedar Mountain." No definite record of this well is available. Its total depth is reported to be about 900 feet; the upper 100 feet are said to consist of clay and sand, below which the drill penetrated shale and red sandstone. Plentiful supplies of good water are said to have been found at the depths of 25 feet, 60 feet, and 80 feet, but there is less certainty as to the amount found in the rock strata. The water did not come to the surface, and that from the deeper sources barely rose to the level of the first ground water. As a small amount of oil was struck, three other wells were sunk by private enterprise. One of these is in the same locality and reached a depth of about 500 feet. Another, situated on the higher ground of "Cedar Mountain," reached a depth of 700 feet, but it is said to have found only a small quantity of water that stood 125 feet below the surface. The third well, situated at the northwest margin of "Bald Mountain" (sec. 15, T. 20 S., R. 5 W.), only

slightly above the level of the low flat, was carried to a depth of at least 1,800 feet, and seems to have penetrated quartzite for much of this distance. The drillers reported that water entered through crevices at different levels and that the quantity was rather great. The water stood about 40 feet below the surface and showed no tendency to rise as greater depths were reached. The location of these wells is shown in figure 11, page 87.

Throughout this region the structure of the rocks is not favorable for accumulating water under artesian pressure. Although in certain localities the strata dip toward the valley, this is not their general attitude, and the extensive fracturing and deformation do not give much reason for expecting flowing water.

In the shallow-water belt there were better prospects of obtaining flows from beds of sand in the unconsolidated sediments, but test wells have here also resulted in disappointment. Wells have been sunk in these sediments to depths of at least 190 feet. In some of them the water rose practically to the surface, but, as far as could be ascertained, no actual flow has anywhere been struck. The failure to obtain flows is probably to be attributed to the absence of a competent barrier on the west to confine the ground water and cause it to accumulate under pressure.

WATER BENEATH THE BENCH LANDS.

Bordering the shallow-water belt on the east is a zone in which many wells have been sunk. In these wells the depth to water increases in general with the distance from the shallow-water belt. (See fig. 11.) The zone in which wells are successful coincides roughly with the zone in which the depth of water is less than 100 feet, but there is reason to believe that for some distance farther up the slope wells could be obtained by sinking to a somewhat greater depth. The water level is, however, likely to be higher near the settlements, where the large streams emerge from the mountains, than in the intermediate meagerly watered tracts.

The conditions in regard to the water table in the vicinity of Holden are the reverse of the conditions commonly found. This village is located at the base of a low cliff that marks the Bonneville shore line, several hundred feet above the bottom lands where the water table comes to the surface. At the foot of the cliff a number of springs emerge and wells find water at very shallow depths. Westward from the cliff the surface descends gently, yet the depth to water increases rapidly until in the northwestern corner of the village it is nearly or quite 100 feet, and 2 or 3 miles farther west

(N. ½ sec. 9, T. 20 S., R. 4 W.), and at a much lower level, there is a dry hole 90 feet deep. In figure 12 is shown the position of the cliff and springs, the location and depth to water of some of the wells, the slope of the surface, and the slope of the ground-water table, both of the latter being shown by contour lines with vertical intervals of 20 feet and referred to an arbitrary datum of 100 feet below the post office. The explanation of the conditions seems to be that a certain amount of underground seepage, instead of sinking at once to its normal level, follows along an impervious formation which comes near the surface at the foot of the cliff, but descends to greater depths toward the west.

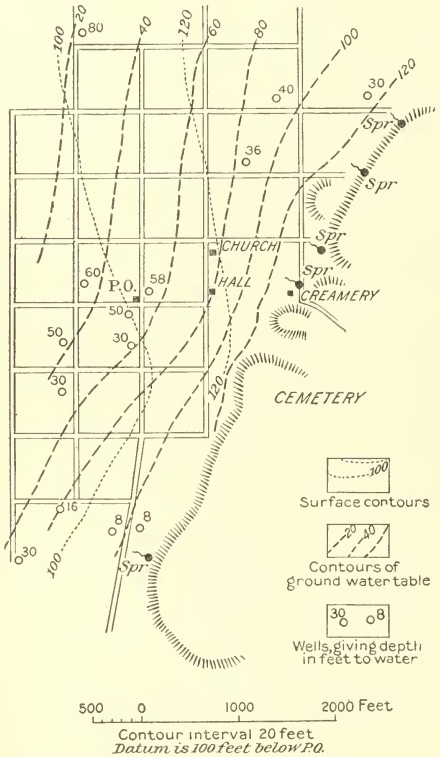


FIGURE 12.—Map of Holden, showing the relation of the ground-water table to the surface.

QUALITY OF GROUND WATER.

In the following table are given two analyses of ground water from this area, both made at the Utah agricultural experiment station:

The first is an anaylsis of water from the well of Daniel Stevens on the NW. ¼ sec. 1, T. 21 S., R. 5 W., a few miles northwest of Fillmore; the well is 50 feet deep and has a normal depth to water of about 35 feet. As shown by the analysis the water contains only moderate amounts of the ordinary mineral substances, in which respect it is probably more or less typical of the water derived from most of the wells in this area and also of that from the springs along the east margin of the shallow-water belt.

The second is an analysis of water from the well on the Kanosh Arid Farm, in the NE. ¼ sec. 16, T. 23 S., R. 6 W., on low level ground several miles west of the village of Kanosh. This well is 42 feet deep, normally contains 4 or 5 feet of water and has yielded as much as 2,800 gallons in a day, or 400 gallons in a period of 30 minutes. The analysis shows that the water is rather highly mineralized, about one-half of its dissolved solid content apparently be-

ing common salt. In the region north of this well there are several springs, including the Warm Spring, that yield mineralized water.

Analyses of ground waters in Pavant Valley.

[Parts per million. Analyst, J. E. Greaves.]

	D. Stevens's well.	Well on Kanosh Arid Farm.
Total solids	520	2,220
Silica (SiO_2)	29	30
Iron (Fe)	Trace.	Trace.
Calcium (Ca)	38	73
Carbonates, stated as calcium carbonate ($CaCo_3$)	258	714
Sulphate radicle (SO_4)	2	294
Chlorides, stated as sodium chloride (NaCl)	89	1,181

IRRIGATION WITH GROUND WATER.

Though flowing water may yet be obtained from wells sunk in unconsolidated sediments in the low-lying bottom lands, it is not probable that such wells would be of much consequence for irrigation because the pressure would probably be so weak that the yield would be small and the water would rise only to the surface of the low ground that is ill adapted for agriculture.

A few years ago an attempt was made by Edgar Warton to irrigate on his land, 4 miles west of Holden (S. ½ sec. 6, T. 20 S., R. 4 W.; see fig. 11), by pumping from wells of large diameter dug to a depth of about 40 feet. The power was at first applied by windmills but a gasoline engine was later installed. At the time the region was visited this project had been abandoned but no definite information was obtained as to the difficulties encountered.

Notwithstanding this apparent failure, it seems probable that a certain amount of irrigation could be successfully accomplished by pumping ground water. There is little doubt that a large supply of good water is available. The greatest danger of failure in this region lies in the alkali in the soil of the shallow-water tracts. In endeavoring to keep the vertical lift as low as possible there is danger of locating on land that is poorly drained and so impregnated with alkali that the project is predestined to failure. Perhaps the best use that can be made of the ground water in this valley, as in Juab Valley, is as a supplementary supply for the latter part of the growing season when the flow of the streams becomes small.

CULINARY SUPPLIES.

In the village of Holden dug wells formerly furnished the domestic water supplies, but more recently there have been installed six small independent pipe lines leading from the springs at the foot of the

cliff along the east margin of the village (fig. 12), and most of the wells have accordingly fallen into disuse. The pressure in the pipes is not sufficient to afford fire protection.

In Fillmore several wells have been dug on comparatively low ground at the north end, but most of the people depend on the stream water. At the time the region was visited, plans were under consideration for the installation of a system of waterworks to be supplied by gravity from a mountain spring.

In Meadow and Hatton the domestic supplies are obtained chiefly from dug wells, which range in depth from about 55 to 90 feet in the former village and from about 30 to 40 feet in the latter.

In Kanosh the only well at present is that of Hyrum Prowse. This well was sunk to a depth of 127 feet and the water rises to a level 91 feet below the surface. It is reported to have been pumped for several hours at the rate of 15 gallons a minute. Two other wells were at one time dug but both have for some reason been abandoned. As in Fillmore, the domestic supply comes chiefly from the irrigation stream and is led to the houses through ditches, but plans are being considered to install waterworks that will be supplied from a spring.

LOWER BEAVER VALLEY.

TOPOGRAPHY AND GEOLOGY.

The Cricket Mountains, a typical basin range, on old maps called the Beaver Range, lie in the south-central part of Millard County and trend in a north-northeasterly direction. Farther south, in Beaver County, the range is continuous with mountains of another name, but at the north end it projects into a flat desert expanse. It is composed of paleozoic quartzites and limestones which for the most part dip toward the east, though in the vicinity of Goss they dip westward, giving this part of the range a synclinal structure. This range contains a few small springs, but it is essentially dry and barren, in which respect it is in strong contrast to the Pavant Range about 30 miles farther east.

The area between these two ranges consists of plains, mesas, and buttes. (See Pl. I.) The part lying south of a line extended westward from Kanosh is largely occupied by low mountains and table lands which are formed in part of stratified rocks and in part of igneous material, and into which the shore lines of the ancient Lake Bonneville have been incised. The part north of this line is occupied chiefly by a plain but contains a number of low tables and buttes of lava and tuff, a large part of which was extruded while the lake was in existence or since its desiccation. At the north end of the area is Pavant Butte (Sugar Loaf Mountain) whose exposed position and unique form make it a notable landmark.

Between the Beaver Range and the volcanic area just described, the valley of Beaver Creek leads northward from Beaver County and opens out upon Sevier Desert. (See Pl. I.) South of Black Rock the valley is broad, flat, and playa-like, but north of this station it becomes constricted between the mountain range and a lava plateau, and it is held within rather narrow limits until it reaches the vicinity of Turner's ranch, where the confining rock walls retreat or disappear. In the area between Cruz and Borden the valley is crossed by a succession of bars and terraces built during the Provo stage of Lake Bonneville, but farther north it expands into a low flat area that merges into Sevier Desert.

RAINFALL.

Lower Beaver Valley and the adjacent uplands appear arid, barren, and desolate. The observations made at Black Rock for the United States Weather Bureau indicate an average annual precipitation of less than 10 inches.

Precipitation (in inches) at Black Rock.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1901	0.40	1.43	0.34	1.29	0.78	0.94	0.15	1.02	0.00	0.56	Tr.	0.70	7.61
1902	.26	.20	1.15	.16	.23	Tr.	.40	.19	.84	.53	1.97	.45	6.38
1903	1.11	1.30	2.00	2.59	1.72	.33	.41	1.75	.92	.95	.10	.18	13.36
1904	4.10	1.00	.93	.26	1.64	.04	.05	.56	.30	.65	.00	.55	6.39
1905	.48	2.26	1.74	1.28	1.52	Tr.	.65	.75	2.57	.88	.....	.....	.....
1906	1.59	.....	.....	3.31	.91	.12	.....	1.12	2.33	.03	2.11	.97	.....
1907	1.85	.78	1.50	.52	1.31	.53	.04	.....	.....	.....	.....	.....	.....
1908	.....	.....	.....	Tr.	1.59	.26	1.17	.80	.....	3.31	.60	.....	.....
Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.43

STREAMS.

The valley of Beaver Creek forms the natural outlet for a large drainage basin that lies to the south of Lower Beaver Valley, and if the climate were more humid it would be occupied by a river; but under existing conditions the streams that rise in the high mountains of Beaver County normally disappear long before they reach this region, and it is only in exceptional freshets that water flows through this part of the valley. At Turner's ranch a reservoir for storing flood water has been built, the dam being at a point where an ancient lake bar is projected across the valley. Pine Creek, in the northeast corner of Beaver County, and Cove Creek, in the southeast corner of Millard County (Pl. I), have small irrigation supplies, but the channel that leads from these small streams to Beaver Creek is normally dry.

SPRINGS.

BLACK ROCK SPRINGS.

In the vicinity of Black Rock station the eastern border of Beaver Valley is formed by the abrupt cliff of a large plateau. In a re-

entrant of this cliff, about 1 mile east and a short distance south of the station, there are three groups of springs that issue from crevices in the lava rock near the base of the cliff. The southernmost group yields the most water. Its flow, measured at different times by the railroad company, was found to average 622,000 gallons per day, or 432 gallons per minute, and to be nearly constant, the daily yield at no time being found to vary more than 10,000 gallons from the average. The water has a temperature of about 58°F. It is of good quality and contains only moderate amounts of the mineral substances usually found in ground waters. The following analyses of water from the south group are reported by the railroad company. No. 1 represents water from the small spring farthest north in this group; No. 2, water from the middle spring; and No. 3, water from the large spring farthest south.

Analyses of water from Black Rock Springs.

[Parts per million.[1] Analyst, Herman Harms.]

	1	2	3
Total solids	397	324	328
Siliceous matter (SiO_2)	48	49	50
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	2.5	1.5	2
Calcium carbonate ($CaCO_3$)	0	69	70
Magnesium carbonate ($MgCO_3$)	11	31	39
Calcium sulphates ($CaSO_4$)	62	27	28
Sodium chloride (NaCl), magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), volatile, organic, and loss	273	146	139

[1] Originally reported in grains per gallon.

A part of the water is led through a pipe line to the station, where it is used in the locomotives and forms the only domestic supply; the rest is used for irrigation on James's ranch, at the springs, where it produces a small oasis in the midst of a large desert.

CLEAR LAKE SPRINGS.

Somewhat more than 30 miles northwest of Black Rock Springs is a group of springs that furnish a larger supply of water for irrigation. These springs are situated east of Clear Lake station and southwest of Pavant Butte, and issue from the margin of the lava bed that extends southward from that butte. They give rise to a small lake that was formerly called Spring Lake but is now locally known as Clear Lake, from which the water naturally discharges into a marshy area to the north but is at present led through a canal to Clear Lake station, where it is used with partial success for irrigation. The following analysis of water from the lake was made at the Utah agricultural experiment station.

Analysis of water from Clear Lake.

[Parts per million. Analyst, J. E. Greaves.]

Total solids	1,003
Silica (SiO_2)	19
Iron (Fe)	Trace.
Calcium (Ca)	77
Carbonates, stated as calcium carbonate ($CaCO_3$)	240
Sulphate radicle (SO_4)	188
Chlorides, stated as sodium chloride (NaCl)	786

OTHER SPRINGS.

These two large springs, or rather groups of springs, both closely related to beds of volcanic rock, are the only ones in the area that yield water in sufficient quantity for irrigation, but several smaller springs are valuable as desert watering places. Among these are Antelope Spring, about 7 miles southeast of Black Rock, the Coyote Springs, about the same distance northeast of Black Rock, and a small spring north of North Twin Butte. There are also several springs in the mountains southwest of Black Rock and one small spring, known as Cricket Spring, on the west side of the Cricket Mountains.

WELLS.

WELLS ON THE BEAVER BOTTOMS.

Between Black Rock and Milford, Beaver Valley constitutes a low flat area, known as the Beaver Bottoms, in which ground water occurs near the surface. Here a number of wells have been dug or drilled, and some of these wells overflow, but the water-bearing sediments are fine, the yield is small, and the water is generally saline. Most of the wells are in Beaver County and have been discussed in the report on that region.[1]

GOSS WELL.

The railway well at Goss is reported to be 1,775 feet deep and to end in granite. According to the section, which is shown in Plate III and is given in detail in the following table, the material from the surface to a depth of 355 feet consists of clay or shale except at three horizons where sand or gravel occurs, and between the depths of 355 feet and 1,584 feet it consists almost exclusively of clay or shale. Salty water was obtained at depths of 195 feet and 350 feet. The yield from the first horizon was about 1 gallon per minute, and from the second about 14 gallons per minute. Near the bottom large supplies were found, but the water, like that at higher horizons, is salty. When 10-inch casing had been inserted to a depth of 1,555 feet the well is reported to have been pumped with

[1] Lee, W. T., Water resources of Beaver Valley, Utah; Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 30.

a Sillett deep-well cable pump extending to a depth of 410 feet for 15 hours continuously at a good many hundred gallons a minute without depleting the supply. Pumping at about 75 gallons per minute was continued for over a year in the hope that the quality of the water would be improved, but, as far as was ascertained, no improvement took place. So great, however, is the need for a supply at this point that the water, bad though it is, is used to some extent in locomotive boilers.

Section of railroad well at Goss.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	12	12
Clay and gravel	25	37
Sticky blue clay	32	69
lay	118	187
Blue waxy clay and brown sedimentary sand (salty water at 195 feet; 1 gallon per minute)	15	202
Blue clay	24	226
Blue clay and shale	18	244
Blue shale	60	304
Blue clay	46	350
Fine sand (salty water; 14 gallons per minute; analysis given below)	5	355
Gray shale	59	414
Soapstone	238	652
Brown waxy clay	96	748
White clay	15	763
Hard blue clay	93	856
Hard soapstone	17	873
Blue clay	347	1,220
Silt shale	42	1,262
Brown clay	38	1,300
Brown clay and rock	12	1,312
Rock	10	1,322
Sedimentary stone	12	1,334
Silt shale	48	1,382
Shale	49	1,431
Soapstone	83	1,514
Soapstone and bowlders	26	1,540
Soapstone	44	1,584
Cemented gravel	17	1,601
Blue limestone	4	1,605
Cemented gravel	5	1,610
Blue limestone	22	1,632
Blue limestone and yellow clay mixed	11	1,643
Granite (a soft streak between 1,770 and 1,773 feet is supposed to be the source of the large supply of water; analysis given below)	132	1,775

Analyses of water from the Goss railroad well.

[Parts per million.[1] Analyst, Herman Harms.]

	Sample from depth of 350 feet, July 25, 1906.	Sample from completed well, Oct. 12, 1907.
Total solids	5,114	3,333
Siliceous matter (SiO_2)	25	23
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	5	17
Calcium carbonate ($CaCO_3$)	51	71
Calcium sulphate ($CaSO_4$)	Trace.	125
Magnesium carbonate ($MgCO_3$)	34	42
Sodium chloride (NaCl)	3,063	2,195
Sodium sulphate (Na_2SO_4), magnesium sulphate ($MgSO_4$), sodium bicarbonate (Na_2CO_3), volatile, organic, undetermined, and loss	1,936	860

[1] Originally reported in grains per gallon.

NEELS WELL.

The railway well at Neels, which is 1,998 feet deep, resembles the Goss well in that it passes through great thicknesses of clay or shale and ends in granite. (See Pl. III and the log given below.) The proportion of coarser sediments is, however, somewhat greater, and water was reported at no less than nine horizons. Six-inch casing was inserted to a depth of 1,425 feet. The largest supplies of water come from the thick beds of gravel and sandstone that occur at about this level, and it is reported that no water was found in the formations below these. W. T. Lee[1] states that the well was pumped at 260 to 300 gallons per minute during a test lasting continuously for 24 hours; H. C. Sillett, who has more recently tested the well for the railroad company, reports that with his deep-well cable pump, in which he used the entire 6-inch casing as the pump-cylinder, he was able to draw water at the remarkable rate of about 2,000 gallons per minute. The water from all horizons is salty. In three analyses reported by Mr. Lee, the chlorine content is, respectively, 1,065 parts, 1,063 parts, and 863 parts per million, and the total solids are 3,336 parts, 3,345 parts, and 2,888 parts per million. Beds of lava and volcanic ash occur at different depths, and the water that comes from the deep sources is hot. As in the Goss well, it was hoped that heavy and long continued pumping might improve the quality, but this hope was not realized. The well has now been abandoned.

Section of railroad well at Neels.[2]

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	4	4
Sedimentary (alkali)	5	9
Fire clay	40	49
Water-bearing quicksand	9	58
Shale and soapstone	21	79
Rock (sedimentary)	6	85
Water-bearing quicksand	3	88
Soapstone	11	99
Soapstone with fossil bowlders	39	138
Water-bearing quicksand	4	142
Fire clay	12	154
Blue waxy clay	34	188
Gray shale and clay mixed	7	195
Gray waxy clay	36	231
Lava rock	12	243
Blue waxy clay	12	255
Sedimentary sandstone	6	261
Blue waxy clay	25	286
Water-bearing quicksand	6	292
Blue waxy clay	28	320
Water-bearing quicksand	7	327
Sedimentary sandstone	10	337
Yellow clay	16	353
Water-bearing quicksand	5	358
Yellow clay	27	385
Blue waxy clay	110	495
Yellow clay	15	510
Sedimentary sandstone	24	534
Blue waxy clay	17	551

[1] Water-Supply Paper U. S. Geol. Survey No. 217, 1908. [2] Idem, p. 33.

Section of railroad well at Neels—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Soapstone	50	601
Blue waxy clay	11	612
Silt	8	620
Water-bearing quicksand	3	623
Yellow clay	53	676
Sedimentary sandstone	12	688
Yellow clay	34	722
Blue waxy clay	117	839
Yellow clay	9	848
Blue waxy clay	210	1,058
Blue shale (sand mixed)	18	1,076
Blue waxy clay	13	1,089
Blue shale	45	1,134
Blue shale (sand mixed); yielded hot water	71	1,205
Red shale	12	1,217
Blue shale	70	1,287
Red shale	24	1,311
Blue shale	28	1,339
Red "keel" stone	6	1,345
Water, sand, gravel, and bowlders	70	1,415
Sedimentary sandstone, brown	35	1,450
Red sandstone	95	1,545
Red shale, burned	35	1,580
Trap rock, dark brown	36	1,616
Red shale, burned	56	1,672
Lava rock with calcite crystals	14	1,686
Red sandstone	68	1,754
Red clay, sticky	48	1,802
Volcanic deposit, ash, and bowlders; gas under pressure sufficient to raise 6,200 pounds of tools 400 feet	105	1,907
Bowlders, cemented	6	1,913
Cavity	9	1,922
Bowlders	22	1,944
Cavity	6	1,950
Granite with crevices and gas	48	1,998

CLEAR LAKE WELL.

At Clear Lake station a well was at one time drilled by the railway company, but it has long since been abandoned, and the data in regard to it are accordingly vague. Its depth was variously reported at 1,335 and 1,380 feet. Water was struck at several depths. According to some accounts the water overflowed with slight pressure, but according to others it remained 4 feet below the surface. No water flows from the well at present. The water was used for a number of years, but was too highly mineralized to be satisfactory for steam making, and the bad quality appears to be the reason for the disuse of the well. At present the culinary supply for Clear Lake is hauled from Oasis by the railroad company.

SWAN LAKE FARM WELLS.

On the Swan Lake farm (sec. 15, T. 19 S., R. 9 W.), about 6 miles west of Clear Lake, there is an old flowing well which is said to be about 600 feet deep and which yields a small amount of water. The water has a distinct taste and in a rough field test was found to contain about 500 parts per million of chlorine. The water is used at the ranch for culinary purposes.

In a well drilled 4 miles farther west, at the headquarters of the Swan Lake farm (about sec. 13, T. 19 S., R. 10 W.), the strata penetrated were chiefly clay, but a number of sandy water-bearing beds were found, all of which yielded salty water and none of which gave rise to a flow. The drilling was carried to 365 feet below the surface, at which depth the hole was abandoned.

Section of abandoned well on the Swan Lake farm.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	48	48
Gravel (very salty water which stood 10 feet below the surface)	7	55
Hardpan with thin layers of sand (salty water)	65	120
Soft light-blue clay	15	135
Light-colored hardpan with 7 strata of sand, each 4 to 6 inches thick (small yield of salty water, which stood 17 feet below the surface)	230	365

SHALLOW WELLS IN THE VALLEY BELOW BLACK ROCK.

For some distance north of Black Rock the valley is narrow and there is no evidence of ground water. At Turner's ranch, where the surface water is to some extent entrapped between bars built by the ancient lake, there is a shallow dug well. On the low flat farther north the ground is generally saturated, especially in the vicinity of irrigated fields, and in many places seepages of poor water can be obtained near the surface.

OLD RIVER BED AND CHERRY CREEK REGION.

GENERAL FEATURES.

Sevier Desert is inclosed on the north by a group of ranges which includes the Champlin, West Tintic, Simpson, McDowell, and Drum mountains. South of the Simpson Mountains lies a rugged area that culminates in a cluster of bald peaks known locally as Desert Mountain, and south of the McDowell Mountains is a lava plateau which is bounded by precipitous walls and which stands prominently above the adjoining plain. (See Pl. I.) The low, flat area of Sevier Desert extends to the region east of this plateau, and farther north contracts into a narrow belt through which passes the Old River Bed. This constricted valley leads between the McDowell Mountains on one side and the Desert and Simpson mountains on the other, to Tooele County and the flat expanse surrounding Great Salt Lake. (See Pl. I.)

Broad open plains extend from the low flat and the Old River Bed into the largest reentrants between the mountains, their surfaces rising gently but continuously toward the mountain borders where

they have an elevation several hundred feet above the low flat or the Old River Bed. One of these amphitheaters extends between Desert Mountain and Simpson Mountains and opens to the Old River Bed. It has no recognized name, but as Judd Creek enters it from the north it can properly be designated Judd Creek Valley. A larger plain of the same character, sometimes called Cherry Creek Valley after the stream that flows into it, lies in the angle between Desert Mountain and the West Tintic and Champlin mountains, and leads out upon the low, marshy tract east of the lava bed. A third large valley lies between the McDowell Mountains, on the east, and the Thomas and Drum ranges, on the west, and leads southeastward to the Sevier Desert flat.

When Lake Bonneville stood at its highest level its waters covered the low flat and the Old River Bed to a depth of 600 to 700 feet, and inundated the sandy bench to the east and the lower parts of all the principal valleys. Cherry Creek Valley and Judd Creek Valley were then bays, and the site of Rockwell's ranch was under water. Desert Mountain formed a rocky promontory connected with the mainland by an isthmus that extended between the bays just mentioned. The McDowell Mountains were completely surrounded by water and the numerous small buttes to the north formed an archipelago of rocky islands. The lava plateau was entirely submerged except for Fumarole Butte, commonly known as "the crater," and a small butte farther northeast. (See fig. 2.)

In the Provo stage the lake covered the low flat and Old River Bed and reached some distance up the central axes of Cherry Creek and Judd Creek valleys, but the lava plateau and the valley to the west were dry land, as is indicated in figure 2. Both the Bonneville and Provo shore lines are marked by beach ridges, terraces, and sea cliffs, and form easily recognized natural datum planes which assist in estimating the altitude and probable depth to water in any given locality. At a later stage, when the lake level was lowered still more, a stream flowed northward through the Old River Bed, as is described by Mr. Gilbert in his monograph on Lake Bonneville.

The relation of the vegetation to the shore lines is significant. In some places shad scale predominates above the Provo shore line and greasewood below it. Owing to the seepage from the large gravel terraces, the vegetation at the foot of these terraces is more luxuriant than it is elsewhere, and greasewood and rabbit brush are dominant. Large sagebrush is found along arroyos through which freshets occasionally discharge, the soil here containing less alkali than in the low areas and receiving more moisture than in other parts of the bench lands.

WATER SUPPLIES.

The principal water supply in this region is furnished by Cherry Creek, which rises in the West Tintic Mountains and flows southwestward, as shown in Plate I. Upon this creek depends Rockwell's ranch (NE. ¼ sec. 30, T. 12 S., R. 5 W.), the so-called Company ranch (SW. ¼ sec. 10, in the same township), and the pumping station (about 5 miles farther northeast), from which a pipe line leads to the Tintic mining district, 20 miles distant. Approximately 150,000 gallons of water is pumped daily from Cherry Creek into Tintic Valley. Only enough water reaches the two ranches to supply the live stock and to irrigate small plats of land.

This region contains a few other small mountain streams, among which may be mentioned Judd Creek, on the south flank of the Simpson Mountains, and a few isolated mountain springs, such as Keg Spring, on the north slope of the McDowell Mountains. None of these furnish much water, but they are valuable as watering places for live stock on the range.

The only other source of water in this region is the Hot Springs situated at the east base of the lava plateau, where hot water issues in large quantities from mounds of variegated hues and gives rise to columns of vapor which, on favorable days, can be seen far out on the desert. Temperatures ranging from 110° to 178° F. were observed by Mr. Gilbert.[1] Certain types of red, yellow, and green algæ live in the hot water and are largely responsible for the bright colors that characterize the locality. The water is strongly saline, the amount of chlorine found in a field test being about 1,600 parts per million. The combined yield from the different openings amounts to several hundred gallons per minute. The water flows unused to the swampy area east of the springs, but on its way, where sufficiently cooled, it produces a meager growth of poor grass. The large quantities of salt in the water and soil of the vicinity prevent the successful use of the water for irrigation. These springs probably owe their origin to fissures in the lava bed and derive their high temperature from the residual heat retained by the lava at some depth below the surface.

GROUND-WATER PROSPECTS.

Owing to the lack of irrigation supplies and of other resources, this region remains almost without permanent inhabitants, and hence there has been little incentive to dig or drill for ground water. Nevertheless in certain sections wells yielding good water could probably be obtained by moderately deep wells.

[1] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 333.

Surrounding the Champlin Mountains and reaching to the foot of the West Tintic Range there is an extensive upland area, much of which is deeply buried in sand. Part of the water that falls as rain on this area sinks into the ground and is probably transmitted to beds of sand and gravel underlying Cherry Creek valley and the low belt of land that extends southward toward the Desert Wells. Much of the run-off from the west slope of the West Tintic Range sinks into the gravelly materials at its margin and is also added to the ground water below the valley. There are, therefore, rather good prospects for obtaining successful wells in the region that lies in general southwest of Rockwell's ranch, and the water that is found will probably be of good quality. However, it is not likely that the ground water stands greatly above the level of the low flat east of the lava plateau, and hence it is only on the lower parts of the slopes from the uplands that the prospects are good for getting water at moderate depths. In the low flat east of the lava plateau the ground-water level is near the surface and flows might possibly be obtained, but there is some danger that the sediments are here too fine to yield water freely or that the water is saline. The alkali in the soil and the poor drainage of the flat are unfavorable for irrigation with ground water even if satisfactory supplies could be developed.

In the valley north of Desert Mountain, here called Judd Creek valley, the conditions are comparable to those in Cherry Creek valley. This valley receives a supply of ground water from the mountainous areas that border it on the north, east, and south, and the water is likely to be of good quality. Both the Bonneville and Provo shore lines are plainly traced upon the great amphitheater that comprises this valley; the Bonneville near the top and the Provo near the bottom. Below the Provo shore line there are prospects for obtaining successful wells at moderate depths.

In that part of the Old River Bed that lies east of the McDowell Mountains there are no indications that the ground water comes to the surface, but the low altitude makes it probable that the ground-water level is within reach of ordinary drilling operations, and there are fairly good chances of obtaining successful wells along the site of this ancient stream channel. Mr. Gilbert's monograph on Lake Bonneville mentions an abandoned well, 100 feet deep, at the old stage station in the River Bed, a short distance beyond the north boundary of Juab County.

DRUM AND SWASEY WASH REGION.

WELLS AT JOY.

In a pass through the Drum Mountains are located the Joy post office and Laird ranch, and near by is the Ibex mine, where a few

miners are at work. This small settlement contains the only permanent human inhabitants that will be found in going from Fish Springs to the settlements in Sevier Desert, or from Trout Creek, in Snake Valley, to Rockwell's ranch, on Cherry Creek. Here are two small but highly prized water supplies. One is at the ranch and comes from a tunnel and other shallow excavations. The other, about a mile farther northwest, is obtained from a well 30 feet deep, and is used by the freighters who operate between Fish Springs and Oasis, and also by the men at the Ibex mine. (See Pl. IV.) The conditions are here similar to those in the Tintic mining district. Where the porous rock waste has not been removed by erosion it collects rain water, and as this water can not penetrate the underlying firm igneous rock it forms seeps that can be tapped at favorable points. Evidently the best localities to prospect for supplies of this kind are where igneous rock occurs and where there is some indication of seepage at the surface. As in the Tintic district, the supply fluctuates with the rainfall, but, as far as is known, the wells have at no time dried up completely.

OTHER WATER SUPPLIES.

The barren and desolate region that surrounds Joy for many miles in all directions is nearly destitute of springs, wells, or water supplies of any kind. The Hot Springs, to the east, and Keg Spring, far to the northeast, have been mentioned in describing the Old River Bed region (pp. 101–104); Wild Horse Spring is 15 miles northwest of Joy, in the Thomas Range; Swasey Spring is 15 miles southwest of Joy, at the east margin of the House Range; Antelope Spring is 5 miles farther southwest, near the summit of this range; and a spring in Granite Canyon is 15 miles still farther south, in the same range. (See Pl. IV.) In the area that lies between Fish Springs flat and White Valley on the west and the Old River Bed and Sevier River on the east these are the only springs worthy of mention.

A prospector is reported to have struck water at a depth of 30 feet about 6 miles south of Joy, the conditions probably being similar to those at Joy. At the site of an abandoned smelter midway between Joy and Deseret, on the road that leads between Drum and Little Drum mountains, there is a well that consists of a hole dug to the depth of 90 feet and drilled with 1½-inch casing from this level to a total depth of 190 feet. The water rises through the casing and fills the dug hole to a level about 80 feet below the surface. The water is reported to be of good quality, but the yield is not large. This well, which is known as the Old Smelter well, forms one of the watering places for the freighters who haul ore from Fish Springs to Oasis.

GROUND-WATER PROSPECTS.

A large valley lies between the Drum and McDowell mountains and leads southeastward to Sevier Desert; a smaller valley lies between the Drum and Little Drum mountains and likewise leads to Sevier Desert; and a large open valley, commonly known as Swasey Wash, intervenes between the Little Drum Mountains and the House Range and leads in the same direction. All three of these valleys lie at considerable elevations above the ground-water level of Sevier Desert and their axes have pronounced gradients. They are therefore probably drained of their ground water to great depths.

The strata of the House Range form an eastward dipping monocline. On the west their edges are exposed and form an imposing escarpment overlooking White Valley; toward the east they gradually pass beneath alluvial and lake sediments. The débris-covered slope that extends from this range to the flat of Sevier Desert is remarkably wide and has a total descent of nearly 1,000 feet. There can be little doubt that the width of the slope is largely due to the underlying eastward-dipping rock strata. The prospects are not good for finding water below this slope. The unconsolidated sediments are likely to be drained, and the limestone and quartzites, which lie below them in a large part of the area, are unpromising as sources of water.

Successful wells may possibly be sunk at the foot of the slope that descends from the House Range and in the areas where the valleys mentioned above merge into the low flat of Sevier Desert. Here the ground-water level is likely to be within reach of the drill and coarse sediments containing fresh water probably exist. On the flat farther east there is more danger of encountering only fine lake sediments, which may not yield freely and whose water may be saline.

SEVIER DESERT.

PHYSIOGRAPHY.

Sevier River, the only large stream that enters the region discussed in this report, follows a devious course. Rising in the high plateau near the south boundary of the State it flows northward for nearly 150 miles in a structural trough, then turns and passes through Little Valley and Sevier Canyon, from which it emerges at Leamington; thence it flows southwestward through Sevier Desert and discharges into the alkaline waters of the playa-like lake that bears its name. (See Pl. I.)

Like the numerous smaller streams of this region Sevier River has built an alluvial fan where it debouches from the mountains, though, in accordance with its greater volume of water, its fan is more ex-

panded and has a gentler grade. When Sevier Desert was submerged beneath Lake Bonneville, the river deposits were built into a delta rather than into a fan, and thus a somewhat complex structure has resulted. In the Bonneville stage the lake level was so high that Little Valley contained a land-locked bay and Sevier Canyon became a strait (fig. 2), and under these conditions the bulk of the stream's load came to repose before reaching the Leamington area. In the Provo stage, which lasted for a long time, the water stood at a level more favorable for building a delta below the canyon.

Sevier Desert may be regarded as consisting of two plains at different levels, the ascent from one to the other being steep enough to form a recognized topographic feature. The upper plain, commonly known as the Lynn bench, is essentially the ancient delta of Sevier River. It occupies the region on both sides of the river as far downstream as the vicinity of Burtner. Here its margin swings back, on one side trending southeast toward the south end of the Canyon Range and on the other side trending somewhat east of north in the direction of Rockwell's ranch. The altitude of this delta plain is approximately that of the Provo shore line, being 4,790 feet above sea level at Lynn, 4,785 feet at Cline, and about 4,770 feet at the Burtner Dam. Since the subsidence of the lake Sevier River has carved a gorgelike valley out of the loose sediments of the delta. At the Burtner Dam the valley has two terraces, one about 20 feet below the upland, and the other about 75 feet lower, or about 40 feet above the present flood plain. The sides of the valley have the castellated appearance of badlands. The walls bordering the present flood plain are conspicuously steeper and more angular than those bordering the terraces.

In the vicinity of Burtner, the river leaves its gorge and flows out upon the extensive low flat that forms the lower plain of Sevier Desert. A few miles farther downstream its valley disappears entirely and it occupies a channel whose banks are on a level with the general surface of the plain or slightly higher. Here the stream is of the aggrading type and frequently changes its course, as is attested by many channels that meander over the plain and in many places form low ridges. In times of high water large portions of this lower plain are inundated and are converted into impassable swamps. Sevier Lake, however, lies at a lower level, and before reaching it the river occupies a definite though shallow valley.

Sevier Desert is nearly surrounded by mountain ranges. The Canyon, Pavant, Beaver, Drum, McDowell, Desert, West Tintic, and Champlin ranges all form parts of the inclosing rock wall, and where gaps occur between these ranges other mountains rise in the background. In contrast to the great relief and the rugged topography

of the mountains, which are always in sight, the vast expanse of Sevier Desert appears flat and featureless and the difference in level between the Lynn bench and the lower plain is inconspicuous. The impression of flatness is heightened through the contrast afforded by the isolated volcanic buttes and mesas which here and there rise abruptly above the floor of the desert. The Lynn bench and the alluvial slopes adjoining the mountains give the desert a total relief of several hundred feet, the gorge in the Lynn bench is locally a conspicuous feature, and the sand dunes and abandoned stream channels break to some extent the monotony of the general surface.

RAINFALL.

Records of precipitation at Deseret and Oak City are presented in the following table. In the 11 years for which the record at Deseret is complete, the annual precipitation ranged between 4.85 and 11.77 inches, and averaged 8.15 inches, which is approximately the same as at Black Rock and Frisco, but is only one-half as much as at Levan and also substantially less than at Scipio, Fillmore, and Oak City. (See p. 19 and fig. 3.) As at other stations in this section of the country, the most rain falls in the spring and the least in the summer. (See fig. 4.) In an average year the precipitation at Deseret during the months of June, July, and August together is only about 1 inch.

Precipitation (in inches) at Deseret.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1891	.....	.....	.....	.....	.....	.....	.....	0.64	0.62	0.05	0.00	0.21	.....
1892	0.53	1.30	1.84	0.71	1.81	0.14	0.42	.58	.06	1.12	.10	.86	9.47
1893	.54	.61	1.85	1.40	.67	.00	.21	.91	.46	.05	.14	.82	7.66
1894	.35	1.35	.53	.64	.43	1.29	.25	.23	1.67	.39	.00	.88	8.01
1895	.40	.53	.63	.84	.....	Tr.	Tr.	Tr.	.80	.45	.84	.38	.....
1896	.32	.....	.29	.47	.....	.....	.....	.....	.....	.....	.....	.....	.....
1899	.....	.....	.....	.....	.....	.....	.....	.....	Tr.	1.23	.34	.80	.....
1900	.36	.05	Tr.	2.85	.10	.03	Tr.	Tr.	1.12	.39	.48	.00	5.38
1901	.10	1.67	.80	1.02	1.90	.62	.03	1.54	.03	.50	.04	.76	9.01
1902	.48	.30	.82	.36	.32	Tr.	.08	.04	.40	.20	1.65	.20	4.85
1903	.94	1.30	.40	.90	1.53	.40	Tr.	.08	.67	.72	Tr.	.05	6.99
1904	.15	.97	1.55	.13	2.13	.60	Tr.	.20	.32	.32	.00	.77	7.14
1905	.42	1.25	1.06	1.36	1.35	.00	.00	1.15	1.79	Tr.	1.25	.13	9.76
1906	.31	.41	2.10	1.63	1.06	.19	.....	.63	.95	Tr.	1.38	.94	11.77
1907	1.66	.82	1.00	.10	2.20	1.07	.04	.29	.87	.60	.20	.79	9.64
1908	.11	.80	1.00	.40	1.10	1.22	.....	.57	2.00	2.15	.25	.34	.....
Average	.48	.87	1.07	.91	1.22	.43	.10	.49	.78	.55	.45	.53	8.15

Precipitation (in inches) at Oak City.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1905	.....	.....	1.83	1.30	1.91	0.00	0.15	0.63	2.29	0.15	1.55	.54	.....
1906	1.09	0.91	3.49	3.28	2.31	.58	.83	1.56	.94	.27	2.15	1.64	19.05
1907	1.80	1.80	1.47	.69	1.69	1.37	1.04	1.15	.91	.69	.12	1.51	14.24
1908	.66	.71	1.15	.57	3.29	.59	.56	.87	2.34	2.55	.....	.86	.....

GROUND-WATER LEVEL.

Much of the water that falls as rain on the mountains and elevated valleys that encircle Sevier Desert migrates, either in surface streams or by underground percolation, toward the low interior. Thus, though in the high areas the ground water is at great depths or may be entirely drained away, in the low interior it has accumulated until it is practically at the surface. The lowest depression is that occupied by Sevier Lake, but the entire Sevier Desert except at Lynn bench and the alluvial slopes near the mountains is so nearly at a level that the ground water is everywhere near the surface, and swamps are found over large tracts extending north beyond the Hot Springs and east to Clear Lake and the region north of Pavant Butte. Sevier Desert thus acts as a huge evaporating pan for disposing of the accumulating water. In the Lake Bonneville stage, when the climate was more humid, the inflow of water was much greater and the rate of evaporation was probably less, with the result that the water accumulated until this entire region was submerged to a depth of several hundred feet.

The fact that this region is the receptacle of surplus surface and ground water and has at the same time an arid climate brings dry and wet areas unexpectedly close together. Thus in the most barren parts of the desert it may be necessary to dig down only a short distance in order to find water, and where the water table comes to the surface the desert gives way to the swamp so suddenly that the traveler may find himself mired where a moment before all seemed dry.

On the Lynn bench the water level is, of course, farther below the surface, but it is probably not beyond the reach of ordinary drilling operations. In the valley at Leamington the ground water stands nearly at a level with the river, and in the well at Lynn it rises approximately to the river level, or within about 100 feet of the upland surface.

SOIL.

The soil and subsoil on the low flat are impregnated with alkalies left behind by the evaporating waters. The following table presents the results of analyses of samples of soil from two localities where conditions have not been modified by irrigation. The first sample was taken on the flat 5½ miles east of Oasis; the second, near the Desert Wells, 7 miles north of Burtner. On the higher ground of the Lynn bench and the slopes bordering the mountains the ground water is not within the reach of evaporation, and for this reason the soil no doubt contains less alkali.

Analyses of soil in Sevier Desert.

[Made by Bureau of Soils, U. S. Department of Agriculture.]

Location.	Depth within which the soil was taken.	Soluble solids (alkali), per cent of total.	Predominating salts in order named.
	Feet.		
No. 1, northeast corner of sec. 3, T. 18 S., R. 6 W., 5½ miles east of Oasis, Utah.	1	0.3	Bicarbonates and chlorides.
	2	3.1	Sulphates and chlorides.
	3	2.6	Do.
	4	2.4	Do.
	5	2.0	Do.
	6	2.6	Do.
No. 2, sec. 1, T. 16 S., R. 7 W., 7 miles north of Burtner, Utah.	1	1.3	Carbonates and chlorides.
	2	1.6	Sulphates and chlorides.
	3	1.7	Do.
	4	.8	Do.
	5	1.3	Do.
	6	1.2	Do.

VEGETATION.

The native vegetation is, of course, all of the desert type, but it differs radically in different sections, according to the degree of aridity, the amount of alkali in the soil, and the depth to ground water.

On the Oak City and Fools Creek benches, where the aridity is not extreme and the soil is not overburdened with alkali, tall sagebrush predominates; on the uplands farther west, especially on the Lynn bench, where precipitation is less and conditions are perhaps more adverse in other respects, the sagebrush gives way largely to shad scale; on most of the low flat, where there is little rainfall and much alkali, but where the ground water is near the surface, tall and luxurious greasewood predominates; on some of the low ridges formed by abandoned river channels, where conditions differ somewhat from those on the alkali flat through which these ridges meander, the greasewood is largely displaced by rabbit brush, and an abandoned channel can sometimes be traced long distances by such a band of yellow-topped brush winding through the monotonous expanse of greasewood; in a few areas, generally near springs, patches of grass are maintaining themselves; and in the impassable salt marshes, salt brush holds undisputed possession. The only tracts where conditions seem to be so adverse that no sort of vegetation is able to obtain a foothold are certain low flats which are usually dry, but which at irregular intervals become submerged, with the result that they are alternately extremely dry and extremely wet. The soil samples whose analyses are given were taken in localities where greasewood is dominant.

IRRIGATION.

The water from Sevier River is used for irrigation at Leamington, Mack, Burtner, Oasis, Deseret, Hinkley, Abraham, and Swan Lake.

These communities have in the past been compelled to contend with two adverse conditions—the breaking of reservoirs and the presence of alkali in the soil. Below Leamington, where the sides and bottom of the river valley consist of unconsolidated material, dams built across the valley have frequently been washed out. The remedy for this difficulty, after much unfortunate experience, is being found in constructing reservoirs farther upstream where rock walls and bottom offer more secure dam sites. The difficulty with alkali has been chronic. With light irrigation the alkali has become concentrated at the surface; with copious irrigation it has been temporarily carried down, but water-logging has resulted. The United States Department of Agriculture has recently made a survey of the region with a view to having established an effective system of underdrainage, by means of which the alkali can be washed away.

WATER-BEARING BEDS.

That this region has been filled to a depth of many hundreds of feet with stream and lake sediments is demonstrated by the deep railroad wells at Oasis, Neels, and Goss. Some of these sediments have been washed from adjacent mountain sides, but most of them have probably been brought by Sevier River. In as far as they are derived from Sevier River it would be expected that they would be coarse near the point where the river comes out of the mountains and very fine in localities most remote from this point, because an aggrading stream deposits its load of gravel and sand first and holds the fine grains of clay in suspension longest. A gradation of this kind is suggested by Plate III: The section at Lynn is made up largely of gravel and sand; that at Oasis contains numerous beds of sand; at Swan Lake farm and Neels the sections have a smaller proportion of sand, and the sand is mostly of the fine-grained variety reported as quicksand; the section at Goss, still farther from the base of supply, consists for hundreds of feet of almost nothing but clay. Since the water-yielding capacity of a bed decreases with the size of its constituent grains, it might be expected that the prospects of getting wells with good yield would be best near the point where the Sevier comes out of the mountains and poorest in the areas most remote from this point, and the well data given in the ensuing paragraphs indicate that this is the case.

WELLS ON THE LYNN BENCH AND CANYON MOUNTAIN SLOPE.

The railroad well at Lynn is of special interest because it is the only well on the Lynn bench. It ends in coarse gravel at a depth

of 235 feet and is cased with 12-inch pipe to a depth of 225 feet.[1] When completed, in 1905, it was pumped continuously for 11 hours at the rate of 108 gallons per minute.

Section of railroad well at Lynn, Utah.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	8	8
Gravel	10	18
Sand	12	30
Sand and gravel	10	40
Sand	20	60
Blue clay	95	155
Blue sandy clay, water-bearing	60	215
Sand	10	225
Coarse gravel, water-bearing	10	235

In the valley at Leamington a group of dug wells, about 20 to 25 feet deep, yield plenty of water for domestic use, but have not been given any severe tests. About 1½ miles southeast of Leamington there is a good well 45 feet deep, belonging to Emil Anderson, but farther south on the alluvial slope of the Canyon Range there are no wells. At Fools Creek settlement two holes have been dug, one 145 feet and the other 110 feet deep, and at Oak City a hole was sunk to the depth of 70 feet. In all three of these excavations gravel and coarse sand were passed through but work was stopped before the water level was reached.

There is reason to believe that water-bearing beds of sand and gravel exist in most places below the Lynn bench and the lower part of the slope on which Oak City and Fools Creek are situated.

WELLS ON THE LOW FLAT.

On the low flat in the vicinity of Deseret, Oasis, Hinkley, Burtner, and Abraham, several hundred successful wells have been sunk. Though water is found within a few feet of the surface, most of the wells are between 100 and 200 feet deep, many are between 200 and 300 feet deep, and a few go to still greater depths. The new railroad well at Oasis was carried to a depth of 710 feet.

The strata penetrated consist essentially of unconsolidated and frequently alternating beds of clay and sand with no bowlders and almost no gravel. The clay preponderates but there are numerous beds of sand of sufficient thickness and coarseness of grain to supply water freely. Several well sections are given to illustrate the character of the strata.

[1] Lee, W. T., Water resources of Beaver Valley, Utah; Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 34.

Section of S. W. Western's flowing well at Deseret, Utah.

	Thickness.	Depth.
	Feet.	*Feet.*
Sandy loam (salty water at 12 feet)	20	20
Red gumbo clay	14	34
White chalk	6	40
Gravel	2	42
Red joint clay	20	62
Clay and sand alternating (salty water which did not flow)	68	130
Light blue clay	30	160
Sand (flow of sulphurous water. Some of the oldest wells end in this stratum)	4	164
Dark clay	3	167
Fine yellow sand (flow of soft water, less sulphurous. Many wells end in this stratum)	43	210
Clay and sand alternating, the clay layers about 3 to 4 feet and the sand beds about one-half foot thick (flows of good water from all the sand beds)	24	234
Blue clay	3	237
Dark coarse sand (flow of one-half gallon a minute of soft water, slightly sulphurous; head about 1 foot above the surface) entered	2	239

Section of E. J. Whicker's well near Burtner, Utah (sec. 23, T. 17 S., R. 7 W.).

	Thickness.	Depth.
	Feet.	*Feet.*
Clay with some sand	19	19
Hardpan	10	29
Soft clay with thin layers of sand	13	42
Coarse sand	15	57
Clay and sand in thin layers	12	69
Soft clay	10	79
Light-colored clay	10	89
Clay	5	94
Mud or silt	6	100
Clay	4	104
Sand	6	110
Clay	5	115
Sand	4	119
Clay	8	127
Red sand	1	128
Hardpan	1	129
Soft clay	8	137
Sand	3	140
Gumbo	6	146
Red and blue clay	8	154
Clay with thin bed of sand	17	171
Soft, light-colored clay	16	187
Sand entered.		

Section of deep railroad well at Oasis.[1]

	Thickness.	Depth.
	Feet.	*Feet.*
Alternating beds of clay and sand, similar to the sections already given	335	335
Sand	15	350
Blue clay	20	370
Red clay	25	395
Sand	13	408
Sandstone	4	412
Blue clay	68	480
Sand	11	491
Red clay	9	500
Blue clay	27	527
Quicksand	3	530
Clay and sand	29	559
Black sand	3	562
Clay and gravel	13	575
Clay	23	598
Cemented gravel	12	610
Soft sandstone	7	617
Clay	6	623
Rock	2	625
Clay	15	640
White clay	16	656
Clay, chiefly yellow	54	710

[1] Lee, W. T. Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, pp. 33-34.

Nearly all of the successful wells are within 10 miles of the margin of the Lynn bench. The farthest north is a group of wells north of Abraham, several recently drilled wells near the north margin of T. 16 S., R. 7 W., and the Desert Wells, near the northeast corner of T. 16 S., R. 7 W. Toward the west wells are found approximately to a line extending from Abraham southward to the river. Toward the south they are found a few miles south of Deseret and Oasis. Toward the east they are found for several miles beyond Burtner and Oasis, and a well was once drilled about 8 miles east of Oasis. Successful wells could probably be obtained farther north and east. In the region south and southwest of the limits outlined, at greater distances from the Lynn bench, considerable drilling has been done, but it was almost invariably unsuccessful. The conditions at Swan Lake, Clear Lake, Neels, and Goss are discussed on pages 97 to 101.

The deep railroad well drilled at Oasis in 1905 is 10 to 12 inches in diameter and 710 feet deep. It passes through a number of water-bearing beds of sand, 10 of which gave rise to flows. At a depth of 335 feet a 15-foot stratum of sand was struck and a flow of about 30 gallons a minute was obtained. In a pumping test the well is reported to have supplied 200 gallons a minute with but slight lowering of the water level. The last part of the drilling was in clay, which yielded no water.

ARTESIAN CONDITIONS.

In a large proportion of the wells of this region the water rises above the surface. Commonly ground water is reached in these wells at a depth of only a few feet; as work continues, the drill passes through successive beds of water-bearing sand which are separated from each other by layers of clay. The water in these beds is under artesian pressure, and as lower beds are reached the artesian pressure increases slightly until beds may be tapped from which the water rises to the surface or a few feet higher. S. W. Western's well in Deseret is typical. Here the first water was found at 12 feet, and below this level water-bearing beds were passed through at short intervals until the drilling was stopped at the depth of 240 feet. The water did not rise to the surface until a depth of 160 feet was reached, below which every water-bearing bed gave rise to a flow. From no horizon in this well was the water under much pressure nor the yield large. In the deep railroad well at Oasis the most copious flow was obtained after the depth of 335 feet was reached.

Throughout the entire low flat portion of Sevier Desert the head of water coincides so nearly with the surface of the land that a swell or depression almost too gentle to be discerned is sufficient to make

the difference between a flowing and a nonflowing well. Flows are obtained in Oasis and in the region immediately north of that village. Exceptionally strong flows are found east of Oasis for about 3 miles, and the abandoned Phillips well, about 8 miles east, indicated that there may here be a considerable area in which wells would obtain flowing water. Flows are found in most of Deseret, and for about 4 miles up the river to sec. 15, T. 17 S., R. 7 W., also north and west of Deseret to a distance of several miles, and in the region between Deseret and Hinkley. In most of the wells in Hinkley the water does not rise quite to the surface, but at the north end of this village there are several flowing wells. South of Deseret and Oasis flows have been obtained nearly as far as Van, but farther south attempts to get flows have generally been unsuccessful, though there is one isolated flowing well on the Swan Lake farm, nearly 15 miles southwest of Deseret. (See Pl. I.)

Another area in which flows have been obtained is north of the river near the margin of the Lynn bench. (See Pl. I.) It contains the group of flowing wells known as the Desert Wells. This area is limited on the east by the high ground of the Lynn bench and on the south by a tongue of elevated land that extends westward from this bench between the wells and the river. Toward the west and north there is low ground with prospects for flows. However, only 3 miles east of the Desert Wells there is a well, belonging to Bruce Seely, which is 182 feet deep and in which the water stands 12 feet below the surface, and 1¼ miles farther northwest there is a well which is 130 feet deep and in which the water stands 14 feet below the surface.

All of the flowing wells with the possible exception of the one on the Swan Lake farm have a relation to the Lynn bench. This large, level, elevated, and sandy region is the principal catchment area from which the water is supplied to the beds of sand that extend beneath the adjacent low flat. Hence, the artesian pressure is best on that part of the flat that lies nearest this bench, and, in spite of the fact that the surface continues to descend, flows are not generally obtained beyond a certain distance from the foot of the bench. The head of water is about 4,700 feet above sea level at Lynn, 4,625 feet at Burtner, 4,600 feet at Oasis, and less than 4,600 feet farther southwest.

QUALITY OF WATER.

The water from the railroad well at Lynn contains only moderate amounts of dissolved mineral matter, and most of the ground water below the Lynn bench and the slope of the Canyon Range will probably be found to be fairly good.

Analysis of water from railroad well at Lynn, Utah.

[Parts per million.[1] Analyst, Herman Harms.]

Total solids	559
Siliceous matter (SiO_2)	93
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	9
Calcium carbonate ($CaCO_3$)	136
Calcium sulphate ($CaSO_4$)	Trace.
Magnesium carbonate ($MgCO_3$)	85
Sodium chloride ($NaCl$)	149
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile, organic and loss	87

Throughout the low flat area the shallow ground water is saline, but in most of the localities in which drilling has been done the deeper beds contain water that is relatively soft and not perceptibly saline. Thus in the water from the flowing well of David Day in Oasis the chlorine content is only 37 parts per million; in the water from the Desert wells, 75 parts; in the water from the well of Bruce Seely, 3 miles west of the Desert wells, 63 parts; and in the water from the well of Peter Christensen, northwest of Abraham (SE. $\frac{1}{4}$ sec. 15, T. 16 S., R. 8 W.), 108 parts. In S. W. Western's well, already referred to as showing typical conditions for the vicinity of Deseret and Oasis, salty water is reported to a depth of 130 feet, but fresh water from all lower beds.

The following is an analysis, made in September, 1910, of the water from the Jensen artesian well, in the northern part of Deseret, Utah. The water is commercially known as the Deseret lithia water. The lithium was not separately determined:

Analysis of water from Jensen artesian well.

[Parts per million. Analyst, James R. Bailey.]

Total solids	581
Silica (SiO_2)	48
Iron (Fe)	.1
Aluminum (Al)	.1
Calcium (Ca)	3.3
Magnesium (Mg)	1.0
Sodium (Na)	209
Potassium (K)	7.8
Carbonate radicle (CO_3)	22
Bicarbonate radicle (HCO_3)	429
Sulphate radicle (SO_4)	28
Chlorine (Cl)	42
Nitrate radicle (NO_3)	.6

Most of the deep water contains hydrogen sulphide gas, which is given off in small bubbles when the water comes to the surface. The

[1] Originally reported in grains per gallon.

stratum which in Deseret and Oasis usually gives rise to the first flow, and which was struck at the depth of 160 feet in Western's well, seems to be especially strongly charged with this gas.

In the southern part of Sevier Desert saline water has generally been found at all depths penetrated by the drill. The flowing well of P. N. Peterson, 1 mile northeast of Van, is 258 feet deep and yields water that contains about 675 parts per million of chlorine. On the farm of J. V. Conk, 4 miles southwest of Deseret, three wells have been drilled, the deepest going to the depth of 227 feet, but the water found was all salty. Deep wells have been drilled at Swan Lake, Clear Lake, Neels, and Goss in the hope of finding good water, but none of these wells has been successful.

The following analysis of water from the railroad well at Oasis is not typical of the best deep water of the region. There is some reason for believing that water from shallow sources enters this well.

Analysis of water from railroad well at Oasis.

[Parts per million.[1] Analyst, Herman Harms.]

Total solids	1,325
Siliceous matter (SiO_2)	45
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	3
Calcium carbonate ($CaCO_3$)	54
Calcium sulphate ($CaSO_4$)	45
Magnesium carbonate ($MgCO_3$)	75
Sodium chloride ($NaCl$)	864
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile, organic, and loss	239

WAH WAH VALLEY.

GENERAL FEATURES.

Wah Wah Valley, which on the old maps is called Preuss Valley, is bordered on the east by the San Francisco Mountains and on the west by the Wah Wah Range and the southern extension of the Confusion Mountains. It lies chiefly in Beaver County, but its lower part extends into Millard County and leads to Sevier Lake. (See Pl. I.) It is a wide, open valley with large alluvial slopes and so few topographic irregularities that from a single vantage point the eye can sweep a large part of its area. In the Bonneville stage the waters of the ancient lake extended far up this valley and formed a distinct strand on its sides; in the Provo stage the lake occupied only the lower part. (See fig. 2.) The axis of the valley descends several hundred feet from its upper end to Sevier Lake, but in one locality between Newhouse and Sevier Lake there is an obstruction back of which a playa has formed. Wah Wah Valley can consist-

[1] Originally reported in grains per gallon.

ently be considered to end with this playa, but it is convenient here to discuss the entire area to the south end of Sevier Lake. West of the lower part of this structural trough and tributary to it lies an extensive and rugged upland area which contains several soil-covered valleys of considerable size.

SOIL.

Samples of soil were taken at the point where the road from Black Rock to Ibex crosses the axis of the valley, and these samples were analyzed by the United States Bureau of Soils, with the results shown in the following table. This crossing is below the Provo shore line and below the playa, but well above Sevier Lake and at a point where the valley has considerable gradient, as is shown by the presence of a dry channel.

Analysis of soil south of Lake Sevier.

Depth within which the soil was taken.	Soluble substances (alkali). Per cent of total.	Predominating salts in order named.
Feet.		
1	0.5	Chlorides and carbonates.
2	.9	Sulphates and chlorides.
3	1.0	Do.
4	1.2	Do.
5	.9	Do.
6	1.3	Chlorides and sulphates.

RAINFALL.

No rainfall observations are recorded by the United States Weather Bureau for Wah Wah Valley, but aridity is plainly shown by the vegetation and surface features. At Black Rock and Frisco the average annual precipitation is between 8 and 9 inches, and at Garrison it is still less. This amount of rainfall has thus far not proved sufficient for dry farming. The data for Frisco are given in the following table:

Precipitation (in inches) at Frisco.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1897	.....	0.30	0.44	Tr.	0.20	0.11	0.16	0.19	1.21	1.50	0.45	1.00	.....
1898	0.42	.10	.12	0.41	2.59	.11	.97	1.46	.00	.31	.15	.24	6.88
1899	.10	.65	2.56	1.01	.08	.36	.81	.18	Tr.	.51	.28	Tr.	6.54
1900	.11	.04	.03	1.73	.....	.04	Tr.	.05	1.41	.77	.55	.05	.....
1901	.35	2.36	.28	.86	1.42	.97	1.76	.64	Tr.	.68	Tr.	.75	10.07
1902	.95	.02	.72	.10	Tr.	Tr.	.74	.82	.47	.15	1.22	.39	5.58
1903	.75	1.66	.68	1.49	1.88	.66	.72	1.12	.82	.85	.02	.07	10.72
1904	.50	.64	.97	.10	2.49	.11	.86	.83	.45	.41	.00	.22	7.58
1905	.66	1.44	1.71	.58	1.44	.02	.58	1.04	2.32	.89	.83	.30	11.81
1906	.10	.56	.....	.....	.....	.....	.....	.....	.....	.....	.98	.95	.....
1907	1.12	.42	.60	.00	.....	.....	.....	.....	.....	.....	.....	.....	.....
1908	.....	.....	1.30	.30	1.58	.49	.42	1.00	1.87	1.57	.00	.60	.....
Average	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	8.45

WATER SUPPLIES.

Wah Wah Valley is entirely destitute of an irrigation supply and contains very few watering places for man or beast. Wah Wah Spring—the only spring of consequence in the region—is situated in Beaver County, on the west side of the valley, and its water is led by gravity through a pipe line to Newhouse, a mining town on the east side. At Kelley's, a short distance north of Wah Wah Spring, a small supply has been developed from surficial sources.

GROUND-WATER PROSPECTS.

Conditions are not favorable for finding ground water in this region. Beneath the broad slopes that flank the valley water is almost certainly at a great depth, and may be entirely absent. Even along the axis of the valley the gradient is in most places so steep and the altitude so much higher than that of Sevier Lake that it is not likely that water would be found near the surface. At the playa the drainage is evidently checked, but there may be no underground structure competent to impound the water that percolates beneath the surface. A drill hole was at one time put down in the valley west of Newhouse with the hope of obtaining a supply for that town. Detailed information could not be obtained, but it is known that the project proved unsuccessful.

In the elevated valleys to the west the rock waste is as a rule not deep, and the underlying formations consist chiefly of limestones and quartzites which are likely to allow the ground water to escape. Small supplies may exist in basins lined with igneous rock, but the chances of finding any such supplies are poor.

SEVIER LAKE BOTTOMS.

FLUCTUATIONS OF THE LAKE LEVEL.

The Pleistocene Lake Bonneville is now represented only by a few small isolated sheets of water and swampy areas that occupy the lowest depressions of the ancient lake bottom. Sevier Lake is the largest of these residual water bodies in the area covered by this report. It receives supplies from Sevier River and loses them by evaporation. As the amount of evaporation depends on the water area, the size of the lake is an expression of equilibrium between inflow and evaporation, between gain and loss.

Mr. Gilbert, in his monograph on Lake Bonneville, states that Sevier Lake was first explored and accurately mapped in 1872 by R. L. Hoxie and Louis Nell, of the Wheeler Survey, and that at that time it was about 28 miles long; its water surface was 188 square

miles in extent; its maximum depth was about 15 feet, and its outline that indicated in Plate I. He also states that in January, 1880, the lake was virtually dry and its bed was crossed on foot where the water had been deepest.

A large part of the water that would normally flow into the lake is now diverted for irrigation and that which still reaches the lake represents an economic loss that should, as far as possible, be stopped. To save all of the water of Sevier River in years of heavy rainfall would, however, require a very much greater storage capacity than is required in years of light or even average precipitation. In 1880 and in several preceding years the water of the river was so nearly monopolized by irrigators that the lake dried up, but since that time, in spite of probable increased use for irrigation, a surplus has again accumulated. The outline of the lake shown in Plate I is copied from a map of Utah compiled by Gilbert Thompson in 1899.[1] In the autumns of 1908 and 1909 a lake existed which was somewhat larger than that indicated in Plate I, but whose margin was separated from the shore line of 1872 by a flat miry belt. The outline of the north end of the lake in 1908 is shown on the topographic map of the Fish Springs quadrangle. (See Pl. IV.)

POSITION OF THE LAKE.

Sevier Lake occupies the lowest depression in the Sevier drainage basin, but this depression is not in the interior of the desert plain, remote from mountain masses, but in a relatively narrow trough between the House and Cricket ranges. The reason for this position is evident. Originally the lowest depression may have been farther from the elevated areas, but the basin was filled to great depths with sediments brought chiefly by Sevier River, and the quantity of material deposited varied inversely with the distance from the point where the river made its exit from the mountains. This was true both when the river discharged into Lake Bonneville and when it was an aggrading stream building an alluvial fan. Hence the locality most remote from the river's exit received the least sediment, was built up the most slowly, and eventually remained at the lowest level. This most remote locality is the present site of Sevier Lake.

QUALITY OF THE LAKE WATER.

The water of the lake is too saline to be used as a supply for live stock. In 1872, in connection with the Wheeler Survey, a sample was taken at a point on the west shore remote from the inflow, and this sample was analyzed by Dr. O. Loew, with the results shown in

[1] Gannett, Henry, A gazetteer of Utah; Bull U. S. Geol. Survey No. 166, 1900, Pl. I.

the following table.[1] During the periods that the lake was dry some of the deposited salt was probably covered with mud or dust which later prevented it from being redissolved. On the other hand, the quantity of water is at present less than in 1872, and this fact tends to make the concentration greater.

Analysis of water in Sevier Lake.[a]

	Parts per million.	Percentage composition of the anhydrous residue.
Total solids	86,400	.....
Calcium (Ca)	120	0.14
Magnesium (Mg)	2,100	2.43
Sodium and potassium (Na+K)	28,900	33.45
Sulphate radicle (SO_4)	17,580	20.35
Chlorine (Cl)	37,700	43.63
		100.00

[a] Recalculated from hypothetical compounds in grains per gallon.

GROUND-WATER PROSPECTS.

The sediments brought to Sevier Lake were not only meager in quantity but fine grained in character, and hence they are unpromising as a source of water supply. The conditions are similar to those on the opposite side of the Cricket Mountains, where unsuccessful railroad wells were drilled. Nevertheless some coarse material was washed down from the adjacent ranges and this material may contain supplies of fresh water. Gravelly water-bearing lenses are most likely to be found at the base of alluvial fans heading in the largest canyons, out of which have come the most gravel and the most water.

WHITE VALLEY.

GENERAL FEATURES.

White Valley occupies a closed basin more than 60 miles long and about 900 square miles in area. It is bordered on the west by the Confusion Range, which separates it from Snake Valley, and on the east by the House Range, which separates it from Sevier Desert. (See Pl. IV.)

The central flat of the valley is about 4,400 feet above sea level. The loftiest part of the inclosing mountain rim is formed by the House Range, whose two highest peaks are Antelope Mountain and Granite Peak, respectively 9,586 feet and 9,725 feet above sea level, or about one mile above the valley flat. The lowest notch in the rim is at Sand Pass, between the House and Fish Spring ranges, where the altitude is between 4,700 and 4,800 feet.

[1] Geog. and Geol. Surveys W. 100th Mer., vol. 3, 1875, p. 114.

The strata of the bordering mountains consist chiefly of Paleozoic limestones and quartzites. In the House Range they dip toward the east, away from the valley, and their outcropping edges form a steep, rugged westward-facing wall which for many miles towers precipitously above the valley flat. In the northern part of the Confusion Range the dip is also toward the east, which here is toward the valley, and the slope from the mountains to the central flat is relatively wide and gentle, like the east slope of the House Range. Hence the valley is asymmetrical, the lowest part lying near the base of the more lofty range. (See Pl. IV.)

The lowest part of the valley constitutes a nearly flat area, many miles long and several miles in average width. In some parts a miniature eolian topography is imposed upon this flat surface, a fantastic landscape being produced by the presence of innumerable hummocks, the tallest of which are 12 to 15 feet high. These hummocks consist chiefly of residual clay held in place by clumps of salt bush or other vegetation, while the surrounding surface has been lowered by wind erosion. In other parts of the flat, probably the lowest tracts where flood waters occasionally collect, the surface is smooth and quite destitute of vegetation of any sort. Toward the south the valley becomes more constricted and trough-like, but the central axis remains low and, with some interruptions, retains its playa character. At the tapering south end it is hemmed in by rock walls.

When Lake Bonneville existed, White Valley contained a large bay, which, during both the Bonneville and Provo stages, was connected with the main body of the lake by narrow straits at the north end. After the water was lowered a short distance beneath the Provo level, the straits were drained and the bay was converted into a lake that had no outlet.

White Valley is uninhabited. Although there are no records of precipitation in the valley, the sparseness of the desert vegetation and the scarcity of water plainly indicate aridity. Almost the only use made of the region is for sheep grazing, the flocks being brought in during the winter when the light snowfall helps to solve the problem of water supply. Ibex, a winter supply station for sheep herders, is situated a few miles west of the southern extremity of the valley. At this point an attempt at dry farming, thus far unsuccessful, is being made.

SPRINGS.

The White Valley drainage basin has no permanent streams and only a few small springs. Two seepage springs are reported near the base of the Confusion Range. One of these, known as Skunk Spring, is said to be about 5 miles east and 1 mile south of the sum-

mit of Cowboy Pass; the other, known as Gregory Spring, about 8 miles farther south. Though they are small and little known, they are valuable watering places for stock on the range.

Antelope Spring is situated in the House Range, about 1 mile east of the divide and one-half mile north of the road leading from Snake Valley to Oasis. (See Pl. IV.) It yields several gallons per minute of good water and is a valuable watering place for travelers.

A group of small springs, including Coyote, Willow, Tule, and South Tule Springs, occur in the low part of the valley. (See Pl. IV.) They are all on the central flat, west of the axis of the valley and near the base of the long slope from the Confusion Range. Coyote Spring consists of a circular depression in which tules are growing. This depression contains water which is evidently supplied from underground sources but which was not overflowing at the time the spring was seen. The water, though perceptibly mineralized, is used for drinking and for watering live stock. The other springs of the group are said to be similar to Coyote Spring. Like Antelope Spring, these springs are used as watering places by persons traveling between Snake Valley and the settlements in Sevier Desert.

At Ibex there is no spring, but storm water collected from a steep mountain side is stored in reservoirs formed out of natural cavities in the rock.

GROUND-WATER PROSPECTS.

There are no wells in this valley, but it is not improbable that in certain localities ground water could be found. The topographic map (Pl. IV) shows that the central flat is about 4,400 feet above sea level, which is not only far below the surrounding uplands but also slightly below the level of Sevier Lake, 200 feet below the level of the flowing district surrounding Deseret, 300 to 500 feet below the water level in Snake Valley, and only slightly above the surface of Fish Springs Flat and the south end of Great Salt Lake Desert. Obviously the ground water of this valley does not escape to the surrounding valleys, and it is therefore probable that it has accumulated in the sediments below the central flat, a condition also indicated by the group of springs on this flat.

Beneath the flat the sediments may be too fine to yield water freely or too heavily charged with alkali to furnish water of good quality. The chances of obtaining satisfactory supplies are better near the foot of the slopes, where the elevation is not much greater than on the flat but where the sedments are likely to be coarser and less strongly impregnated with alkali. Localities near the mouths of the largest canyons are the most promising. The central part of the tapering southern appendage of the valley has a low altitude nearly to the south end, and may have ground water at moderate depths.

Most of the extensive west slope and the steep east slope of the valley lie so high above the flat that their ground water is no doubt either far below the surface or entirely drained away. In the elevated tributary valleys near the south end the prospects of finding ground water, except at great depths, are also poor, especially where limestones and quartzites are present and igneous rocks are absent.

FISH SPRINGS VALLEY.

GENERAL FEATURES.

Fish Springs Valley is bounded on the east by the Thomas Range and on the west by the Fish Springs Range. Both of these ranges consist of westward-dipping limestones and quartzites with associated masses of volcanic rock, the latter being especially abundant in the Thomas Range. On the east side of the valley the rocks dip toward the center of the valley and the slope is correspondingly wide and gentle. This slope is continuous with the high tract that shuts in the valley on the south, and slope and high tract together form a large upland area. On the west side of the valley the strata have apparently been faulted up and their outcropping edges form a precipitous mountain wall at the base of which is a steep and narrow alluvial slope that diminishes in size toward the north until it almost disappears. At the foot of the slopes from the east, south, and west is a broad swampy alkali flat that merges on the north with the desolate expanse of Great Salt Lake Desert. The only permanent inhabitant in this drainage basin of nearly 400 square miles, is to be found at Thomas's ranch, near the northwestern extremity of the valley, but the Fish Springs and Drum mining camps are located on the mountain rim, just beyond the divides. (See Pl. IV.)

SPRINGS.

No permanent streams rise in the mountains, and the only mountain spring worthy of mention is Wildhorse Spring in the main Thomas Range, 4 miles south and 11 miles east of Thomas's ranch. However, in the central flat, near the base of the Fish Springs Range, there is a group of springs some of which are large.

The Hot Springs, which are located on the flat a short distance from the north end of the Fish Springs Range and less than 1 mile south of the Tooele County line, include a group of tuffaceous mounds with vents from which water is flowing, or has flowed in the past. Hydrostatic equilibrium exists between the water in the different springs, and hence the springs that have the highest mounds have

only a small yield or are extinct, while the most copious flow observed comes from a vent around which almost no mound has yet been built, and which therefore discharges at a lower level. The spring that supplies the bathhouse issues from a mound about 25 feet in diameter and yields several gallons per minute. The water has a temperature of 104° F., is highly mineralized, and deposits incrustations of salt. The water from the large spring has a much higher temperature. A variety of colors, including red, brown, bright green, olive green, and black, are displayed in the vicinity. They are due to chemical precipitates and to filamentary algæ that thrive in the hot water. The large mounds that yield little or no water are distinguished by their bright red color, which is probably due to more complete oxidation of the precipitates at these places than in the vicinity of more active springs.

Between the Hot Springs and the mountain there are two small springs that yield water of lower temperature, and about 1 mile southeast of the Hot Springs is the Big Spring. The latter is located on the flat within a few yards of the foot of the mountain, the alluvial slope here being virtually absent. It consists of a deep pool which has vertical or overhanging walls, and is filled with clear water that issues at the rate of several hundred gallons per minute. Other springs are located at Thomas's ranch and between the ranch and Big Spring, and a number of large springs issue along a line extending to a little over a mile south of the ranch. Most of these springs, like the Big Spring, consist of deep, steep-sided pools filled with clear water, which is supplied from underground sources and which rises by artesian pressure and overflows at a nearly constant rate. The pools are inhabitated by small fish for which the springs are named.

Although these springs are known as "cold springs," in distinction from the Hot Springs, they are thermal in the sense that the temperature of their water is higher than the normal temperature of the shallow ground water of the region. The water in the spring at the ranch has a temperature of 78° F., which is nearly 30 degrees above normal. This water is not excessively mineralized and is freely used for drinking.

About 7 miles south of Thomas's ranch is Cane Spring, which consists of a number of seeps at the base of the alluvial slope. The water is highly mineralized but is used for live stock and forms one of the supplies for the freighters operating between the Utah mine and Oasis.

The Devils Hole, which is near Cane Spring but a little farther up the slope, is a deep circular hole filled with water within 10 or 15 feet of the top. Beneath the water surface, which is about 15 feet in diameter, the walls are overhanging, as in some of the pools

of the Fish Springs. This hole has been described by G. K. Gilbert,[1] who states that "it appears to be due to the undermining action of subterranean currents flowing in channels sufficiently open to permit the removal of even coarse detritus, and the salinity of the water suggests that these channels may have been opened by the solution of deposits of salt."

The Fish Springs Range has evidently been produced by faulting, the break in the strata occurring along the east side. Moreover, very recent faulting is shown by a small fresh scarp which runs parallel to the east margin of the range and in which the alluvial and lacustrine sediments have been displaced.[2] The linear arrangement of the Fish Springs along the east side of the range, together with their high temperature and copious yield, suggests that their origin may be associated with the fault.

WATER IN UTAH MINE.

The Utah mine, which is near the north end of the Fish Springs Range, was sunk through limestone near a contact of intrusive rock. It appears that the first water was found between the depths of 800 and 820 feet, which is somewhat lower than the level of the springs in the valley. The water comes in small quantities from crevices in the rock. It contains a large amount of common salt, but it is the only supply at the mine and is used for drinking and other purposes.

Analysis of water from Utah mine.[3]

[Parts per million; analyst, C. C. Crismon; date, September, 1901.]

Total solids	2,255
Volatile and organic matter	239
Silica (SiO_2)	18
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	13
Calcium (Ca)	64
Magnesium (Mg)	67
Sodium and potassium (Na+K)	591
Sulphate radicle (SO_4)	164
Chlorine (Cl)	1,096

GROUND-WATER PROSPECTS.

In general the best chances of obtaining satisfactory wells are at the base of the slopes, near the margin of the central flat (Pl. IV). Beneath the flat itself the ground water is probably near the surface but it is likely to be poor in quality and, if fine-grained lake

[1] United States Geog. and Geol. Surveys W. 100th Mer., vol. 3, 1875, p. 110.
[2] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, p. 353.
[3] Recalculated from hypothetical combinations in grains per gallon.

sediments prevail, its yield is likely to be small. Farther up the slopes the water probably stands at great depths or has been drained away entirely. Small supplies, similar to those developed at Joy, may exist near the surface in certain localities in the hills and mountains to the east and south where igneous rocks occur.

SNAKE VALLEY.

GENERAL FEATURES.

Snake Valley is a structural trough that trends in a direction somewhat east of north. (See Pls. I and IV.) From its head, in Nevada, it extends diagonally across the State line, passes through the western parts of Millard and Juab counties, and opens upon Great Salt Lake Desert. On the east it is bordered by the low, barren ridges of the Confusion Range; on the west, by the lofty Deep Creek Range, in western Juab County, and by high mountains farther southwest in Nevada. The length of this trough from the vicinity of Burbank to where it merges into Great Salt Lake Desert, near the Tooele County line, is about 80 miles, and its total drainage area within the State of Utah is approximately 2,000 square miles. Its axis descends toward the north but not with equal gradient in all parts. (See Pl. IV.) The valley may be considered to consist of three sections: The upper section includes the part south of Garrison and is sometimes called "Lake Valley," the middle section stretches from Garrison to Trout Creek and forms Snake Valley proper; the lower section extends north from Trout Creek. The middle and lower sections are shown in Plate IV.

In the highest stage of Lake Bonneville the lower and middle sections of Snake Valley contained a large bay (fig. 2) and the upper section was traversed by a tributary river described as follows by Mr. Gilbert:[1]

> A large channel whose habit indicates a stream comparable with the smaller rivers of the basin, enters Snake Valley from the south at a point just east of Wheeler Peak, known as the Snake Valley settlement [Garrison]. The channel ends at the margin of the old lake, and appears to have contained a stream tributary to the lake, which disappeared at the same time. It is now occupied near the settlement by a streamlet from the adjacent mountain known as Lake Creek, but this enters the channel at its side, and played no important part in its formation. Above its confluence the channel has essentially the same dimensions, and these continue as far as it was traced, about 20 miles from its mouth.

In the Provo stage the middle section was virtually drained and the bay extended only a short distance south of Trout Creek.

Conspicuous shore features were constructed by the waves in Snake Valley Bay. Especially characteristic are large terraces bordered on the outside by heavy embankments resembling railroad grades and

[1] Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, pp. 184, 185.

forming "natural reservoirs." So perfect and regular are these embankments that they are believed by some of the inhabitants of the region to represent the labors of an ancient people.

RAINFALL AND VEGETATION.

The rainfall records of the United States Weather Bureau, given in the following table, although not very comprehensive, plainly indicate an arid climate, the precipitation in some years being less than 5 inches. These records are corroborated by the character of the native vegetation. The broad, gravelly slopes that flank the valley on both sides contain only a meager cover of dry, stunted bushes. In the axial portion of the valley, where ground water is near the surface, rabbit brush, greasewood, and salt brush are found, the dominating type among these three in any locality depending largely on the amount of alkali in the soil. The Confusion Range, like the Basin ranges that lie farther east, is notably barren; but the Deep Creek Range, which is several thousand feet higher, supports large trees and evidently receives more moisture than either the valley or the Confusion Range.

Precipitation (in inches) in Snake Valley.

Garrison.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1903	0.66	0.60	0.20	0.38	1.16	0.54	0.05	0.55	0.38	0.23	Tr.	Tr.	4.75
1904	.07	1.49	.62	.06	.97	.41	.93	.95	.55	.94	0.00	0.22	7.21
1905	.37	1.30	.30	.99	1.83	Tr.	.10	.83	.85	.00	2.14	.11	8.82
1906	.....	Tr.	2.47	1.58	.77	.06	.33	.....	.50	.10	1.98	.58	.....
1907	.64	.55	.90	Tr.	.42	.20	.21	.05	.05	.64	.49	.20	4.35
1908	.25	.89	.16	.10	.47	.10	.65	.56	.....	1.41	.33	.26	.....
Average	.40	.81	.77	.52	.94	.22	.38	.59	.47	.55	.83	.23	6.28

Trout Creek.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1905	.....	1.45	0.95	0.25	0.60	0.00	0.00	0.75	1.67	0.00	1.25	0.23	.....
1906	0.14	.43	.92	1.18	1.92	1.70	.28	1.00	1.22	1.20	2.20	.15	12.34
1907	1.85	.51	1.05	.00	.79	.69	Tr.	1.56	.37	.52	Tr.	.95	8.28
1908	.50	1.40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Callao.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1902	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.44	0.28	.....
1903	0.50	.....	.....	Tr.	2.56	.....	0.05	Tr.	0.31	0.18	.16	.07	.....
1904	1.50	0.83	1.16	0.28	.77	1.52	Tr.	0.54	.36	.76	.00	.05	7.77
1905	.05	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Precipitation (in inches) in Snake Valley—Continued.

Fish Springs (Utah Mine).

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1899										2.40	0.37	0.73	
1900	0.05	0.80	0.05	4.65	0.20	0.07	0.70	Tr.	1.37	.42			
1901	22					.24	.25	Tr.	.00				

SPRINGS AND STREAMS.

Some parts of Snake Valley have flowing water during most of the year, but other parts of the axial region are normally dry or are occupied by alkali flats or salt marshes. If the climate were humid, or perhaps if it were only somewhat less arid, a permanent stream would flow through the entire length of the valley. The barren Confusion Range has no streams and is almost destitute of springs, but the loftier and better-watered mountains west of the valley give rise to a number of small irrigation streams. In the succeeding paragraphs the different streams and springs are described in the order in which they are found in passing northward through the valley.

Big Spring and Lake Creek.—Big Spring is situated in Nevada, about 10 miles up the valley from Burbank. The water issues in large volume from gravel not far from a limestone cliff that borders the valley on the west. This water appears to be of good quality. Its temperature was found to be 63.5° F. The spring gives rise to Lake Creek, which flows northeastward to the Burbank settlement and into the reservoir shown in Plate I. For some miles below the Big Spring smaller springs well out of the gravel and help to augment the size of the creek. The flow of the creek below these springs is reported to be 18 second-feet. The water is used for irrigation on six ranches at Burbank, above the reservoir, and on five ranches at Garrison, below the reservoir, but its duty is apparently low. A mile or more south of the reservoir a large spring, known as Burbank Spring, issues from the gravelly bench on the east side of the valley and supplies water of good quality, the temperature of which is 57° F. Another spring exists in the same vicinity, but nearer the creek.

Snake Creek.—A small stream, known as Snake Creek (Pl. I), rises in the mountains west of Garrison and furnishes the irrigation supply for two ranches at this settlement. Its flow is largely provided by the melting of snow at high altitudes.

Baker Creek.—About 7 miles north of Garrison, Baker Creek enters the valley from the west. (See Pl. I.) Its surplus waters join those from Snake and Lake creeks and flow northward along the axis of the valley toward Conger's ranch, producing a swampy tract. There are also springs in the vicinity of Conger's ranch, and small springs, known as Cane Springs, occur several miles west.

Knoll Springs.—The Knoll Springs comprise several groups of springs which are arranged along a north-south line. They are on the east side of the valley, but on low ground. (See Pl. IV.) The southernmost group is near the road leading from Meecham's ranch to Cowboy Pass, about 7 miles east-northeast of the ranch. Some of these springs consist of pools with overhanging walls, but more characteristic are those that consist of mounds, or knolls, near the top of which the water issues. The largest of these knolls are over 100 feet in diameter and more than 10 feet high. Apparently the knolls have been built over pools by the growth of vegetation and the accumulation of dust, as is explained on pages 44 and 45.

The shelves of the pool springs tremble when they are stepped upon, and horses or cattle that venture too far out on them are likely to break through and become mired, but the knolls are so firmly built that they can be traversed with impunity by man and beast. As far as was observed, none of the springs has a large flow, but those which have no knolls or only small ones, and which therefore issue near the level of the normal land surface, yield more than those which discharge at a higher level near the tops of well-developed knolls.

The water does not seem to be highly mineralized. From some of the springs bubbles of hydrogen sulphide were seen to escape, probably resulting from the decomposition of the vegetable matter with which the springs are surrounded. The temperature of the water in one spring was found to be 70.5° F.

Kell Springs, etc.—About halfway between Smithville and Butson's ranch, along the road to Garrison, are four springs known as the Kell Springs (Pl. IV). They are on the west side of the valley but not greatly above the central flat. The most northerly of the group consists of a swampy seepage area, about 30 feet in diameter, covered with water cress. Water that is cool and good to the taste flows from the spring, but is soon lost by seepage and evaporation. A short distance southeast of this spring there is a mound, approximately 75 feet long, 30 feet wide, and 5 feet high, from an orifice at the top of which a small quantity of water issues. A few rods farther south is a small pool of clear water overgrown with cress, the flow from which amounts to several gallons per minute. The water is good to the taste and has a temperature of 58° F. A few rods still farther south there is a mound, more than 100 feet long and perhaps 5 feet high, from three points near the margin of which water flows at the rate of several gallons per minute.

At Butson's ranch a small spring of good cold water issues from a gravelly bank on the valley slope and a small amount of water comes from a canyon to the west. Other streams in the vicinity are Henry Creek, used for irrigation on Meecham's and Simonson's ranches, and Smith Creek, used on George Bishop's ranch at Smithville.

Warm Springs.—A mile or more west of Gandy post office, which is situated high up on the alluvial slope on the west side of the valley, there is a small mountain that consists of distorted and steeply dipping limestone strata. The Warm Springs issue from crevices in the rock at the base of the precipitous south slope of this mountain, and give rise to a stream (Pl. I) that is estimated to be larger than Lake Creek, and whose flow is said to be independent of seasonal changes. The temperature of the water coming from the largest vents is 81.5° F. Calcareous precipitates are found in large quantities at the springs, and they form thick incrustations on the sides and bottom of the stream channel. Deposits of this kind in the vicinity of the springs show that water once issued at points that are now dry. Algæ and water cress abound in the stream. The water appears to be only moderately mineralized and is used for domestic purposes and for irrigation on the ranch of James Robison, on the fields of a small Indian settlement near by, and on a ranch farther down the valley. The total acreage irrigated is not large, and the water is evidently not doing full duty.

Springs at Foote's ranch.—A large group of pool and knoll springs is situated on low ground on the east side of the valley, between 1 and 2 miles south and southeast of Foote's ranch, which is in sec. 9, T. 16 S., R. 18 W. (See Pl. IV.) Most of the pools are surrounded and partly inclosed by marginal shelves, and their clear waters are inhabited by small fish. The largest knolls are about 10 feet high. The flow of these springs is not noticeably affected by seasonal changes, and their total yield amounts to a number of second-feet. The water appears to be of good quality, and its temperature, in five springs that were tested, ranges between 66.5° and 68° F. The spring having the largest yield consists of a pool which is about 125 feet in diameter and is said to be 40 feet deep.

Springs bordering the Salt Marsh.—Numerous springs are found on the west side of the Salt Marsh, which lies north of Foote's ranch. Some of these springs consist of small pools, but in others the water seeps or wells up directly from the porous ground. None are large, but together they yield much water. The temperature of the water in the so-called Cold Spring is 55° F., and in the spring at C. A. Conklin's (the old Gandy ranch) it is 58° F. Neither of these is of the pool type.

The flow of these springs is said to be least in the summer and greatest in the fall. In the fall and winter the Salt Marsh fills with water, which disappears in the summer, but this may be due more largely to a difference in the rate of evaporaton than to differences in the yield of the springs.

Springs between Salt Marsh and Trout Creek.—North of the Salt Marsh the axial part of the valley contains a number of pool springs

which discharge into swampy tracts. The largest spring of this group that was observed is at Miller's ranch, about 8 miles south of Trout Creek. It consists of an oval pool about 125 feet long and 75 feet wide, around which a dam several feet high has been built. The discharge from this pool is several hundred gallons per minute. The water does not appear to be highly mineralized. Its temperature at the outlet was found to be 64° F.

Springs at Trout Creek.—In the lowest part of the valley, at Trout Creek post office, there is an area of seeps and small springs some of which are of the pool type. The temperature of the water in one spring was found to be 55° F.

Springs and streams in Pleasant Valley.—Pleasant Valley heads in Nevada and leads southeastward to Snake Valley, which it enters between Trout Creek and Gandy. (See Pl. I.) A small stream which issues from Water Canyon, to the north, furnishes the irrigation supply at Henroid's ranch, and other canyons furnish still smaller supplies. Along the axis of the valley there are numerous springs some of which yield copiously.

Streams from the Deep Creek Range.—Deep Creek Range is exceptional among the basin ranges of the region in that it gives rise to a number of permanent streams (Pl. IV). Some of these are on the west side and are tributary to Deep Creek, which flows northward into Tooele County; others drain the east slope and provide small quantities of irrigation water for the lower section of Snake Valley. The waters of Birch Creek and Trout Creek are led to the Trout Creek settlement where they furnish the irrigation supply for two ranches, and the waters of Indian Farm Creek, Thoms Creek, and Basin Creek are led to Callao where they supply three ranches.

Willow Springs and similar springs farther north.—At Callao, near the Tooele County line, there is a swampy area that contains a labyrinth of pool springs of various sizes, together known as the Willow Springs. Some of the pools barely overflow but others give rise to vigorous streams. They contain fish and abound in water cress. Redding Spring, another large spring of the pool type, is situated 6 miles farther north.

Character of the springs.—From the foregoing account it is evident that this valley, from Big Spring, 10 miles south of Burbank, to Redding Spring, 6 miles north of Callao, is characterized by an abundance of large springs, most of which, together with the Fish Springs and Hot Springs, exhibit certain traits in common.

Not only are many of the springs large, a number yielding over one second-foot and a few yielding several times this amount, but, according to local reports, the flow of the large springs is not affected by seasonal changes.

The pools and knolls are distinctive of the group, though they do not include the Big Spring nor the Warm Springs, which are the largest springs in the valley. The pools and knolls are found only on low ground, not much above the bottom of the valley, but the Warm Spring is at a much higher level. Characteristic of the pools are their depth, their overhanging shelves, the fish they contain, and the abundance of water cress and other vegetation that they support.

Characteristic also of many of the pools, and of the Big Spring and Warm Springs as well, is the high temperature of their water. The mean annual temperature of this region is about 50° F., in contrast with which the following maximum temperatures were observed in springs:

Temperature (°F.) of spring water in Snake and Fish Springs valleys.

Hot Springs	Near boiling.
Warm Springs	81.5
Fish Springs (small spring at Thomas's ranch)	78.0
Knoll Springs	70.5
Springs at Foote's ranch	68.0
Spring at Miller's ranch	64.0
Big Spring	63.5

Considerable difference in temperature usually exists among the different springs of the same group, the warmest water being where the flow is most copious. This relation was found, for example, in the Hot Springs, Warm Springs, and springs at Foote's ranch. The temperature of the water in large pools with little discharge is no doubt affected by atmospheric conditions.

The origin of these springs is discussed on pages 43–45.

WELLS AND GROUND-WATER PROSPECTS.

Burbank.—In the valley of Lake Creek, above the reservoir, the ground-water level is near the surface, and shallow dug, drilled, or driven wells yield copious supplies of good water. On the farm of B. P. Hockman, 2 miles north and one-half mile east of Burbank post office, two wells have been drilled on ground only a few feet above the creek level, one to a depth of 18 feet and the other to a depth of 40 feet. In sinking these wells alternate beds of clay, sand, and gravel were passed through. The first water was struck at the depth of 9 feet and at 18 feet a good supply that rose by artesian pressure within 4 feet of the surface was obtained.

Considerable quantities of ground water no doubt exist in this part of the valley and could be made available for irrigation by a small lift, but it is improbable that good artesian wells could be obtained. In the lower part of White Sage Valley (also known as Antelope Valley), pump wells can probably be obtained at moderate depths,

but in the middle and upper parts of this valley the ground water is likely to be far below the surface or to be drained away entirely.

Garrison.—In the vicinity of Garrison the depth to water decreases toward the north. In this part of the valley a number of wells have been sunk, most of which have fallen into disuse. Abandoned wells are reported as follows: SE. ¼ SW. ¼ sec. 6, T. 22 S., R. 19 W., a dug well 40 feet deep; SW. ¼ SE. ¼ sec. 31, T. 21 S., R. 19 W., a dug well 35 feet deep; SE. ¼ SE. ¼ sec. 31, T. 21 S., R. 19 W., a dug well 30 feet deep; NW. ¼ SW. ¼ sec. 32, T. 21 S., R. 19 W., a dug well 15 feet deep. A well at the hotel, sunk almost entirely through gravel, receives a small supply of water from seepage near the bottom. At the south end of the settlement (SE. ¼ NW. ¼ sec. 7, T. 22 S., R. 19 W.), two unsuccessful attempts were made to obtain flows. One hole is reported to have been sunk to a depth of nearly 200 feet, at which level bedrock was struck.

Between Garrison and Conger's ranch.—The old Conger ranch is situated in a low, swampy area that receives the drainage from the creeks farther up the valley. At this point a well was drilled which is said to have reached a depth of more than 100 feet and to have found a supply of good water that rose within 3 feet of the surface.

In the low tract traversed by Baker Creek ground water could probably be found in some abundance, and it is possible that in the lowest parts flows would be struck. The large branch valley on the east side of Snake Valley, and heading in the direction of Ibex, receives less water than Baker Creek Valley, but up to some distance beyond the 5,000-foot contour, as shown in Plate IV, there is a reasonable chance of obtaining wells at moderate depths and with supplies sufficiently large for stock purposes.

Between Conger's ranch and Trout Creek.—In the entire stretch between Conger's ranch and Trout Creek the ground is saturated with water virtually to the level of the surface along the axis of the valley, and wells can probably be obtained on the central flat and near the foot of the alluvial slopes, especially on the west side.

A number of shallow wells sunk on the west side of the valley yield water of satisfactory quality and in sufficient amount for domestic and stock purposes. On the ranch of William Meecham (sec. 21, T. 18 S., R. 19 W.), situated about 90 feet above the center of the valley, there is a dug well 28 feet deep which yields water that is somewhat hard, but otherwise good. Two similar wells, one 12 feet and the other 18 feet deep, are situated at a little lower level on this ranch, and a well of the same type supplies Simonson's ranch in the same locality.

On the ranch of George Bishop (NW. ¼ sec. 3, T. 17 S., R. 19 W.), there are two dug wells, one 35 feet and the other about 45 feet deep. The water level here fluctuates considerably, and the wells, at first

more shallow, have been deepened several times to procure a permanent supply. The water is hard but otherwise good and is used for drinking and for culinary purposes.

At the old Barry ranch, near the banks of the Salt Marsh, there is an abandoned dug well in which the water stood 14 feet below the surface.

The two ranches at Trout Creek, situated near the central axis of the valley, obtain their culinary supply from wells 15 feet deep in which the water level fluctuates with the season. The water in these wells is considered of good quality though harder than the stream water. On Alfred Bishop's ranch a 2-inch well was at one time sunk to a depth of over 200 feet in quest of flowing water, but the project was not successful.

Pleasant Valley.—Several wells sunk in Pleasant Valley obtain satisfactory culinary supplies, but attempts to get flows in this valley have thus far been unsuccessful.

Trout Creek to Callao.—Trout Creek is situated in a constricted part of Snake Valley, south of which the valley trough is relatively flat and swampy, but north of which it descends at a rate of about 25 feet per mile until it begins to merge with the desert flat. North of Trout Creek the benches on either side of the valley are high and wide and the valley proper is relatively low. These high benches, especially the one on the west side, receive large contributions of water which is transmitted to lower levels, and there is therefore reason to expect that in the lower parts of the valley good supplies can be obtained at moderate depths. Probably, however, the axial gradient is too great to allow the ground water to accumulate under sufficient head to give rise to flows.

The only well reported in this region is a 50-foot dug well on the claim of Harry Parker, near the center of the valley, not far from the line between secs. 34 and 35, T. 12 S., R. 17 W. Most of the material excavated in sinking this well was compact clay, but near the bottom, quicksand, sand, and water-bearing gravel were found. The yield is reported to be ample and the quality satisfactory, but the water is under little or no artesian pressure.

Callao.—In the northern part of Juab County, Snake Valley expands into Great Salt Lake Desert and a large alluvial slope extends from the Deep Creek Range to the desert flat. In the vicinity of Callao, where the slope from the mountains gives way to the dead level of the desert, and where the Willow Springs, already described, are located, a number of flowing and nonflowing wells have been sunk. Ground water is here reached within a few feet of the surface, as, for example, in the dug well of E. W. Tripp, which is only 12 feet deep and is filled with water to within 3 feet of the surface.

The flowing wells are 1½ to 2 inches in diameter and range from about 40 to 175 feet in depth. Their section consists of clay, sand, and gravel, the largest flows thus far obtained coming from coarse gravel at depths of 90 to 100 feet. In most wells the water rises only a few feet above the surface, but original heads of 15 feet and more are reported. Toward the west the flowing area is sharply limited by the rise in the surface of the land. Flows are obtained on F. G. Kearney's and R. E. Bagley's ranches, but farther west the water remains below the surface. Toward the east, in the direction of the desert, the limits of the flowing area are less definitely known, but satisfactory flows have been obtained as far as 2 miles east of the Kearney ranch buildings. (See Pl. I.)

One of the best wells of this group is near the house of F. J. Kearney, in the SE. ¼ sec. 1, T. 11 S., R. 17 W. It is 2 inches in diameter and 93 feet deep and ends in coarse gravel, from which the water will rise to a level 6 feet above the surface, while at a level 1 foot above the surface the flow is about 20 gallons per minute.

The water from the flowing wells is, as a rule, of better quality than the shallow ground water. The following table contains an analysis, made at the laboratories of the Utah agricultural experiment station, of water from one of the flowing wells at the residence of F. J. Kearney. This sample, which is believed to be typical of the well waters of the Callao Basin, contains only moderate amounts of the mineral constituents generally found in ground waters.

Analysis of water from flowing well of F. J. Kearney, Callao, Utah.

[Parts per million. Analyst, J. E. Greaves.]

Total solids	249
Silica (SiO_2)	16
Iron (Fe)	Trace
Calcium (Ca)	38
Carbonates, stated as calcium carbonate ($CaCO_3$)	228
Sulphate radicle (SO_4)	4
Chlorides, stated as sodium chloride (NaCl)	126

Between Callao and Fish Springs.—The northern part of Juab County between Callao and the Fish Springs Range, into which Great Salt Lake Desert extends, lies so low and is so nearly level (Pl. IV) that the ground-water table nearly coincides with the surface. Desert and swamp are here intimately associated, and the same tract is frequently converted from one to the other. Yet the prospects for obtaining satisfactory wells are not good. The region formed a part of the bed of ancient Lake Bonneville, and the sediments beneath it are likely to be too fine to yield water freely and too heavily impregnated with salt to furnish water of good quality.

The unfavorable conditions found in parts of Sevier Desert are likely to be found here also. In general the prospects both as to quantity and quality become poorer as the distance from the Deep Creek Range increases.

Many years ago two 2-inch holes were sunk on the flat near the west base of the Fish Springs Range, the location being approximately sec. 13, T. 11 S., R. 15 W. According to current report, they reached a depth of about 300 feet, where drilling was stopped by hard rock. The water that was found was salty and remained about 10 feet below the surface. One of the wells was finished, however, and for a number of years its water was used at the mine for live stock, laundry, and toilet, and, to some extent, for drinking purposes.

Another hole was drilled on the flat near the old stage station known as Boyd, in or near sec. 21, T. 11 S., R. 15 W. This project was also unsuccessful but definite information as to the difficulties could not be obtained.

IRRIGATION.

The amount of land irrigated in Snake Valley is small as compared with the amount of water furnished by streams and springs. This is due in part to the fact that some of the largest supplies can not be led by gravity upon land adapted for agriculture, but also in part to the fact that available supplies are not used to their full capacity. Much water could be saved if adequate storage facilities could be provided. Some of the "natural reservoirs" formed by the waves of Lake Bonneville are in positions where they could be brought into service at relatively small cost, but it has not been demonstrated that they could be rendered sufficiently waterproof to make their use feasible. Some water could probably also be saved by practicing winter irrigation.

The water from many of the large springs in the low parts of the valley serves no useful function except to produce the growth of a small amount of poor grass. The chief obstacle to the use of these springs for irrigation lies in the poor drainage and alkali character of the soil upon which the water can be led. Whether it could be made profitable to pump this water to higher and better land is doubtful.

Practically the only irrigation now accomplished with water from wells is at Callao, where a few small tracts are watered from flowing wells. In certain parts of the valley, already indicated, considerable quantities of water could be recovered from underground sources, but pumping would generally be required to make these supplies available on good soil. At Callao the quantity recovered by natural flow could be increased if a series of wells of large diameter were sunk.

PAROWAN VALLEY.

PHYSIOGRAPHY AND GEOLOGY.

Parowan Valley lies at the northeast base of a high plateau from which it is separated by a fault scarp several thousand feet high—the northward continuation of the Hurricane Ledge. On the face of this escarpment and in the canyons that have been cut into the plateau since its differential elevation are exposed the edges of several rock series that have a great total thickness, display a variety of rich colors, and cover a wide range of geologic time. The highest sedimentary strata—bright-hued Tertiary deposits—are covered in some places with somber-colored volcanic rocks.

Parowan Valley is separated from Rush Lake Valley by a mountainous region that is several miles wide and consists of sedimentary strata and associated dark volcanic rocks. This mountainous region is traversed by several faults and the strata dip in different directions. Farther southwest the valley is separated from Rush Lake Valley by only a low pass which projects from the high plateau to the mountainous west wall. On the north the valley is shut in by a mountainous area in which volcanic rocks are abundant. The lowest notch in the rim of the basin is formed by Hieroglyph Canyon, which has been cut boldly through the west wall. (See Pl. II.)

According to the best available data, the Parowan drainage basin comprises between 550 and 600 square miles, nearly two-thirds of which belongs to the plateau. Since the Tertiary deformation, which apparently brought the basin into existence, the plateau has been greatly eroded and the resulting sediments have in large part been deposited in the valley. Since only small amounts of rock waste were brought into the valley from the west, the alluvial slope on the east side comprises most of the valley, and Little Salt Lake, which occupies the lowest depression, hugs the west border. Near the plateau the slope is steep, but near Little Salt Lake it passes into a flat plain with only slight gradient.

Not all of the material eroded from the plateau has remained in the valley, for the drainage of the basin once had an outlet through Hieroglyph Canyon, and the outflowing stream carried some rock waste with it. The valley lies above the level of the highest stage of Lake Bonneville, but there can be little doubt that when the ancient lake existed the climate was sufficiently humid to cause a stream to flow out through the canyon. Possibly the canyon was formed at this time, but more probably it is the work of a stream which was in existence before the west wall of the valley was raised and which maintained its course by cutting down its channel as rapidly as the region was lifted. That the canyon has long ago fallen into disuse is shown

by the talus and alluvium that has accumulated in it and also by the salt that has accumulated in the lowest depression of the valley. An indistinct strand, perhaps 20 feet above the present level of Little Salt Lake, shows that this lake has at one time had larger dimensions than it has at present.

RAINFALL.

The records of the United States Weather Bureau, given in the following table, show that during a period of 18 years, from 1891 to 1908, inclusive, the annual precipitation at Parowan ranged between 7.04 and 20.87 inches, and averaged 12.54 inches. Large sagebrush is prevalent on the alluvial slopes of this valley. Dry farming has not been extensively undertaken, but much interest is at present manifested in this mode of agriculture and it will probably be given a thorough trial in the near future. That the plateau receives more precipitation than the valley is shown by the trees and other vegetation which it supports.

Precipitation (in inches) at Parowan.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1890	.....	.....	.....	.....	.....	.....	.....	.....	0.93	0.59	0.43	0.34	.....
1891	1.46	2.07	2.57	1.57	1.14	0.20	1.24	0.76	2.10	.00	.00	1.13	14.24
1892	.47	1.03	1.79	2.03	.83	.04	.66	1.24	.00	2.32	.20	.39	11.00
1893	.84	1.03	1.23	1.42	1.34	.00	2.08	1.65	1.11	Tr.	1.38	.72	12.80
1894	1.65	.85	2.65	1.27	.55	.57	.78	1.40	.72	.65	Tr.	1.88	12.97
1895	1.94	2.82	1.93	.47	.87	.06	.70	.23	.29	.58	1.28	.90	12.07
1896	.16	.48	.71	.83	.93	.08	1.69	3.00	.47	.36	.30	.16	9.17
1897	1.50	3.45	3.76	.95	.51	.02	.79	1.56	1.84	2.48	.73	.88	18.47
1898	1.99	1.20	1.66	.64	3.35	.24	1.19	1.46	.25	.30	.72	.82	13.82
1899	.12	1.10	2.18	1.20	1.19	.82	.72	.82	.08	.78	.31	1.60	10.92
1900	.51	.23	.18	2.64	.61	.13	.11	.84	.82	.56	.34	.07	7.04
1901	.63	1.84	.85	1.61	.88	.50	.04	3.35	.04	.32	.03	.96	11.05
1902	1.18	.31	1.83	.21	.18	.06	.49	.76	.50	.61	1.86	1.03	9.02
1903	1.10	.77	1.94	1.66	1.10	.49	.41	1.46	1.00	2.03	Tr.	.53	11.89
1904	.43	1.46	2.11	1.27	2.07	.07	.98	1.23	.17	.74	Tr.	.79	11.32
1905	.52	1.54	2.29	.66	1.99	Tr.	.75	.37	3.80	.12	1.11	.32	13.47
1906	1.40	.93	3.99	1.95	.62	Tr.	1.71	3.10	3.49	.41	2.09	1.18	20.87
1907	1.15	1.58	1.61	1.23	2.85	.31	.34	.65	.33	2.16	.32	1.20	13.73
1908	.86	1.19	.62	.39	1.16	.16	2.16	.49	1.64	1.61	.50	1.02	11.80
Average	1.00	1.33	1.88	1.22	1.23	.21	.94	1.28	1.03	.88	.61	.84	12.54

STREAMS AND MOUNTAIN SPRINGS.

Parowan Creek.—The largest stream in the basin is Parowan Creek, which supplies the village of Parowan with water for irrigation. Like other streams of its type, its flow is very irregular, generally being largest in May and June when the bulk of the snow in the mountains melts. Much of the flood water and winter discharge are lost. In October, 1908, the flow was estimated to be 15 second-feet. The total area irrigated with this supply is reported to be about 2,000 acres.

Red and Little creeks.—Red Creek and Little Creek furnish the irrigation supply for the Paragonah settlement. The water in Red Canyon comes largely from springs and its volume varies less than

that of streams which depend chiefly on the melting of snow. In October, 1908, the discharge from Red Canyon was about one-half as great as from Parowan Canyon. The Red Canyon water is reported to irrigate about 800 to 1,000 acres, and the water from Little Creek, a short distance north, about 300 acres.

Streams and springs north of Little Creek.—The only streams of any consequence north of Little Creek are Willow Creek and Cottonwood Creek, which together are said to furnish enough water to irrigate about 100 acres. Buckskin Valley, high up in the mountains, has three good springs which supply a large number of cattle. There is also a spring in Fremont Pass and several others near the north end of the basin.

Streams and springs south of Parowan Creek.—The largest supply south of Parowan Creek comes from Summit Creek and is used for irrigation at the village of Summit. There is also a small supply at the Winn Ranch, a short distance west of Summit, and there are numerous springs along the margin of the mountain between Parowan and Summit, some of which are used to irrigate small tracts.

VALLEY SPRINGS.

Many springs occur in the valley along a line extending southeastward from Buckhorn Spring, where the steep part of the alluvial slope gives way to the nearly level plain that occupies the lowest part of the valley. Many of the springs consist of small pools, in which respect they resemble somewhat the Fish Springs and the springs in Snake Valley. They furnish good supplies for live stock and culinary purposes but do not yield enough to be of much value for irrigation. Many small springs, some of which yield salty water, occur on both sides of Little Salt Lake.

FLOWING WELLS.

Flowing wells have been obtained throughout an area that is about 16 miles long and extends from a point 1 mile northeast of Buckhorn Spring to a point several miles west of Parowan, as is shown in Plate II. Most of the best flows are found along the spring line or a short distance east of it, but flows have also been obtained at various points on the flat between the spring line and the salt lake. Several score of flowing wells are at present in use and new wells are being sunk.

The flowing water is derived from deposits of sand and gravel interbedded with layers of clay, and the artesian conditions do not depend on the structure of the rocks. It is not obtained from a single bed nor from several definitely recognized beds, but from all porous materials below a certain level. In many wells the first flow

is struck at a depth of about 70 feet, but as the drill penetrates deeper it is likely to discover stronger flows from beds of gravel that are more freely porous and that contain water under slightly better head. The deepest flowing well reported is about 400 feet deep, and many of the largest yields are derived from wells between 200 and 300 feet deep, but most of the wells are less than 200 feet deep. The water from these wells has not been analyzed but is apparently of good quality.

The wells thus far drilled are all small, most of them being 2 inches, and a few 3 inches, in diameter. They are finished with heavy iron casing, and water is usually admitted into them at only one level. Many of the wells flow less than 10 gallons per minute, but a few of the 3-inch wells yield from 25 to nearly 100 gallons per minute. In none of the wells is the water under much pressure.

The largest flowing well supplies have been developed on the farm of J. L. Lowder (secs. 25, 26, and 35, T. 33 S., R. 9 W.), where 14 wells furnish water for irrigating about 100 acres; on the farm of Frank Culver (NE. ¼ sec. 9, T. 34 S., R. 9 W.), where about a dozen wells together yield more than one-half second-foot; and on the farm of James C. Robison, 2 miles south of Buckhorn Spring, where a number of flowing wells furnish water for irrigation. On several other farms irrigation supplies are obtained from flowing wells.

The wells of Frank Culver, all of which are within several rods of each other, discharge into a small reservoir, from which the water is led to irrigated fields. The following table gives the principal facts in regard to this group of wells.

Wells of Frank Culver, Parowan Valley, Utah.

No.	Diameter.	Depth.	Temperture of water.	Natural flow.
	Inches.	*Feet.*	° *F.*	*Gallons per minute.*
1	2	.....	49.8	11
2	2	.....	49.8	5
3	2	.....	50.3	5
4	2	180(?)	52.3	4
5	3	233	52.4	37
6	2	50	50.0	13
7	2	160(?)	50.0	11
8	2	.....	51.5	5
9	3	140	51.0	40
10	2	50	51.0	23
11	3	202	53.0	50
12	3	242	53.3	43
Total	.....	.....	.....	247

The inhabitants of this valley have only recently come to realize that supplies of substantial value can be developed by drilling wells, and further development is being prosecuted with enthusiasm. The conditions warrant sinking test wells to greater depths than have

thus far been reached. The faulted structure of the basin makes it probable that the unconsolidated sediments are very thick, and the deeply buried sediments are likely to contain beds of gravel with water under good head. Drilling should not, however, be carried into bed rock. The California method of drilling wells, described on pages 60–64, could be introduced to good advantage in this valley.

As the supply of underground water is a definitely limited quantity, none of it should be wasted. Unless it is found practicable to build reservoirs of sufficient size to store the water which the flowing wells would yield during the winter, these wells should be closed at the end of the irrigation season. If the number of wells is greatly increased they will interfere with each other. Eventually it may be found profitable to install pumping plants rather than to depend entirely on artesian pressure, because more water could be recovered by pumping, and it could be applied to more productive soil. On the higher levels of the alluvial slopes there are no prospects of securing flows, and the success thus far attained should not lead to costly drilling experiments on high ground or in rock formations.

WATER BENEATH THE BENCH LANDS.

A number of nonflowing wells have been sunk on the lower part of the alluvial slope directly west of Parowan and in other localities. These wells yield good water which remains at a depth proportionate to the elevation of the surface above the flowing area. Good pump wells can generally be obtained by sinking to moderate depths on the lower and middle parts of the alluvial slopes.

CULINARY SUPPLIES.

In the three principal settlements of this valley the supplies for drinking and culinary use are taken from the streams which furnish the irrigation supplies or from ditches leading from these streams. Water from springs in the canyons or on the mountain sides, if led to the settlements through pipe lines, could be protected from pollution, and would therefore be safer for drinking and culinary purposes than the stream water.

RUSH LAKE VALLEY.

PHYSIOGRAPHY AND GEOLOGY.

A great fault with a throw of several thousand feet extends northeastward through Iron County, passing Kanarraville, Cedar City, Summit, Parowan, and Paragonah. East of the fault the rock formations have been thrust relatively upward, producing a high plateau with a steep escarpment known as the Hurricane Ledge. Since the displacement the edge of the plateau has been carved by

stream erosion into a mountainous area. This escarpment forms the east border of Rush Lake Valley as far north as the vicinity of Enoch, where it swings eastward and forms the border of Parowan Valley, while a low range that trends more nearly northward forms the divide between Rush Lake and Parowan valleys.

West of the southern part of Rush Lake Valley are the Iron Mountains, but these mountains disappear toward the north, leaving only a low divide between the northern part of this valley and the Escalante Desert. There are two other low points in the rim of Rush Lake Valley. One is at the Iron Springs, where there is an outlet for the drainage of a part of the valley; the other is in the vicinity of Kanarraville, where an inconspicuous divide is all that separates Rush Lake Valley from the drainage basin of Colorado River. (See Pl. II.)

The rocks exposed in this region have a great total thickness and include Carboniferous, Jurassic, Triassic, Cretaceous, and Tertiary strata. The youngest formations are exposed in the northern part of the plateau area of this county and older beds come to light farther south. The Jurassic, Triassic, and Tertiary formations have conspicuous colors, but the intervening Cretaceous beds have a somber gray aspect. Volcanic rocks of Tertiary age are found on the plateau, in the Iron Mountains, in the range between Rush Lake and Parowan valleys, and in the area southwest of Cedar City.

Rush Lake Valley exhibits the characteristic features of a closed basin in an arid region. Its peripheral parts consist of broad, open, alluvial slopes, and its central part consists of a nearly level plain, the lowest depressions of which are occupied by lakes, swamps, and dry alkali flats. The alluvial slopes and central plain are underlain by sediments which were washed out from the mountains and which consist of alternating beds of gravel, sand, and clay.

A low divide, extending from the mouth of Coal Creek Canyon to Iron Springs, separates the valley into two basins. The south basin drains into a small salt lake known as Shirts Lake. (See Pl. II and fig. 13.) The north basin is drained in part into Rush Lake, but the water from Coal Creek may come to rest in depressions farther south or may find its way into Escalante Desert through the valley at Iron Springs.

RAINFALL.

The rainfall observations at Cedar City cover only a few years, but they indicate that the precipitation at this point does not differ greatly from that at Parowan, where the record extends over a much longer period. That the climatic conditions in Rush Lake Valley are similar to those in Parowan Valley is also indicated by the general aspect of the vegetation. Dry farming has been attempted on a small scale and some success has been attained.

Precipitation (in inches) at Cedar City.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1899	.....	.....	.....	.....	.....	.....	.47	1.00	Tr.	1.03	.39	1.18	.....
1900	.81	.29	.22	3.65	.34	.11	.46	.61	1.18	.39	.38	.....	.....
1905	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	3.36	.54	.....
1906	.68	1.28	3.78	1.77	.72	.....	.....	.....	1.56	.10	2.07	1.31	.....
1907	.93	1.31	1.58	.88	2.63	.34	1.16	2.43	.53	3.24	.20	.93	16.16
1908	.55	1.44	.77	.38	1.16	.15	2.45	1.23	2.30	2.31	.32	.67	13.73

STREAMS.

Coal Creek, the largest stream that discharges into Rush Lake Valley, collects its waters in the plateau area and debouches from its canyon at Cedar City. Here it furnishes enough water to irrigate about 3,000 acres, of which 1,700 acres come under the primary water right. Owing to lack of storage facilities, a large part of the winter flow and of the flood waters resulting from heavy storms, runs to waste.

Shirts Creek rises on the plateau in an area south of Coal Creek drainage basin, and its water is used by the small settlement at Hamiltons Fort, where between 200 and 300 acres are under cultivation. The flow of this stream fluctuates widely, being generally greatest in the spring when the snow melts. An attempt was made to store the flood waters, such as are at present lost, by utilizing as a reservoir the basin formed by the volcanic rocks that occur some distance west of the mountain border, but these rocks are so badly fissured that they allowed the water to escape.

Kanarra Creek provides the irrigation supply for the settlement at Kanarraville. Like Shirts Creek it rises on the plateau, receives much of its water directly from the melting of the snow, and hence fluctuates greatly in size. Some water has been stored in a reservoir south of the village. The total area brought under irrigation is reported to be somewhat less than 300 acres.

Several very small streams are found in the Iron Mountains, among which are Queatchupah Creek, whose supply is used to irrigate about 50 acres at McConnell's ranch (fig. 13), and the streamlet in Leach Canyon, which is utilized at the Duncan ranch.

SPRINGS.

Ward's ranch is in the NE. $\frac{1}{4}$ sec. 12, T. 34 S., R. 11 W., about 5 miles north of Enoch, and near the base of a cliff of volcanic rock that belongs to the mountainous area between Rush Lake and Parowan valleys. At this ranch there is a group of springs which yield approximately one second-foot of water. The water issues on low ground, where it gives rise to a swampy tract, but, as far as possible,

it is used for irrigating grass land. The origin of these large springs seems to be associated with the volcanic rock.

Volcanic rock similar to that found at Ward's ranch forms a low ridge east of Enoch and separates the relatively high bench land in the vicinity of Summit from the lower level of Rush Lake Valley. Near the west base of this ridge, along a line extending northward from Enoch for more than a mile, there are numerous springs, some of which are large. Considerable water also issues from springs in a small canyon cut through the ridge. The water is derived, at least in part, from saturated sediments east of the ridge, the fissures in the volcanic rock probably having a function in conducting it. The water is of good quality and is used for irrigation, although some of it issues at too low a level to be applied advantageously.

A number of small springs are found on the low ground that surrounds Shirts Lake. Among them are Eight-mile Spring, situated a short distance northwest of the lake on the NW. ¼ sec. 16, T. 36 S., R. 12 W., and Mud Springs, situated a short distance south of the lake on about the NW. ¼ sec. 9, T. 37 S., R. 12 W. (fig. 13). There are also seepage springs in the valley west of Kanarraville.

Iron Springs are located in the valley that leads from Rush Lake Valley, through the northern part of the Iron Mountains, into Escalante Desert. The water issues at different points along a stream channel which passes through this valley. In part the springs seem to result from the overflow of the ground water that saturates the sediments of Rush Lake Valley, much as some of the Enoch Springs result from the overflow of the ground water in Parowan Valley. Accordingly their yield varies with the season, being greatest in the spring, when some of the surface waters of Rush Lake Valley are discharged through this outlet, and least in the fall and the winter, when the water supply is meager. At the time the area was visited, October, 1908, nearly a second-foot of water issued from the springs and flowed through the stream channel. This water is used to only a small extent for irrigation but forms a valuable supply for live stock. The Church ranch, near the springs, is important as the halfway house between Cedar City and the railway station at Lund.

FLOWING WELLS.

Webster's well.—The well of Francis Webster is situated on low ground a few miles southwest of Enoch, in the NE. ¼ SE. ¼ sec. 14, T. 35 S., R. 11 W. (Pl. II). It is 2 inches in diameter and 153 feet deep. The water is rather hard, but apparently otherwise of good quality and has a temperature of about 54° F. When the well was completed the water remained at a depth of 7 feet, and for seven years it had to be pumped in order to bring it to the surface, but in July,

1907, it began to overflow, and from that time until October, 1908, when the investigation was made, it overflowed continuously. At the latter date the natural yield was about 3½ gallons per minute. This interesting rise in the head of the water is probably to be correlated with increase in rainfall. The records for Parowan show that in 1900, the year in which the well was drilled, the precipitation was lighter than in any other year within the period of 18 years during which records have been kept at that station, and that in each year from 1899 to 1904, inclusive, the precipitation was below the average. These records show further that in 1906 the precipitation was heavier than in any other year within the 18-year period, and that in 1907 it was again above the average. The records at Cedar City also show unusually light precipitation in 1900 and unusually heavy precipitation in 1907.

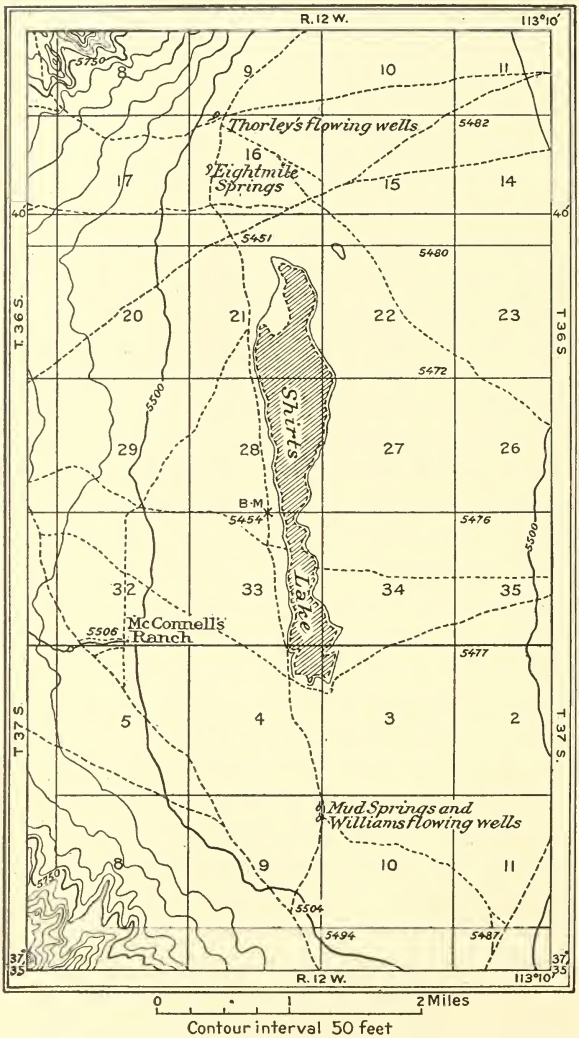


FIGURE 13.—Map of a part of the south basin of Rush Lake Valley.

McConnell's well.—A small flow is reported from a well that belongs to Mr. McConnell and is situated in Cedar Bottoms several miles west of Webster's well.

Thorley's wells.—About half a mile north of the Eightmile Springs, near the northwest corner of sec. 16, T. 36 S., R. 12 W. (fig. 13), are four flowing wells which belong to A. Thorley. They are small

in diameter and are said to be only 80 or 90 feet deep. The water is apparently good but the natural flow is very slight.

Williams's wells.—Five flowing wells have been drilled by George Williams in the vicinity of Mud Springs, south-southeast of Shirts Lake. (See fig. 13.) The first was drilled in about 1892 and is two inches in diameter and 85 feet deep. In this well the first water was struck 8 feet below the surface, and the casing extends only to this depth. According to report, the flow was about 20 gallons per minute when the well was completed, but it is now much less, probably owing to deterioration of the well.

The other four wells, which are located nearly a mile farther west, are 2 inches in diameter and about 90 feet deep. One is cased to a depth of 80 feet, the others only to 8 feet, where the first water was struck. Each of these wells is said to have flowed about 5 gallons a minute when they were completed, but they have since been neglected and their yield has diminished. They are situated on somewhat lower ground than the Thorley wells, which fact may account for their larger original flow. The water is good to the taste and was found to have a temperature of 54.5° F.

In this locality Mr. Williams has drilled to the depth of 240 feet, the drill apparently passing through unconsolidated sediments only. He states that in drilling to this depth five or six beds were struck that gave rise to flows, some of them stronger than the 90-foot flow, and that all the water is of good quality.

Wells at Kanarraville.—On low ground less than 1 mile west of Kanarraville there is a well, belonging to William Ford, which is reported to be considerably less than 100 feet deep. In the past this well yielded a small amount of water by natural flow but at the time it was visited no water flowed from it.

In the village of Kanarraville, at a somewhat higher altitude than Ford's well, a 2-inch hole was drilled to a depth of 240 feet. Mr. Williams, the driller, reports that several water-bearing strata were found and that water from the depth of 190 feet rose within 1 foot of the surface. The drill was finally lost and the well was abandoned.

NONFLOWING WELLS.

In northern part of valley.—At Ward's ranch (NE. $\frac{1}{4}$ sec. 12, T. 34 S., R. 11 W.) a well 2 inches in diameter was drilled to a depth of 250 feet, the last 13 feet of which are said to be in volcanic rock. The water comes from the bottom and rises within 8 feet of the top of the well, or nearly to the level of the flat area west of the well. The water is of good quality and is used for drinking and other purposes. Less than a mile north of this ranch another 250-foot well is reported, the water here rising within 4 feet of the surface. Other

wells have been sunk in the bottoms farther west, in all of which the water stands within a few feet of the surface.

Several shallow wells have been dug in the vicinity of Enoch. The well of Hiram Jones, which is located on the narrow bench between the ridge and the bottom lands, is 20 feet deep and is filled with water within 6 or 8 feet of the top; the well of J. H. Armstrong, situated on lower ground near the foot of the bench, is only 12 feet deep; the well of William Grimshaw, southwest of Enoch, on the W. ½ of SW. ¼ sec. 12, T. 33 S., R. 11 W., is 17 feet deep and contains 3 feet of water; the well of John Webster, about 1 mile south of Enoch, is 30 feet deep; the well of David Bullock, on the W. ½ sec. 24, T. 35 S., R. 11 W., was 48 feet deep and contained 10 feet of water until recently when the sides caved in and the well fell into disuse. Wells of the same type, many of them abandoned or in bad repair, are found at different points on Cedar Bottoms. Most of the wells that have been mentioned yield good water, but in some of the wells on the bottoms the water is salty.

In southern part of valley.—At Hamiltons Fort a depth of 100 feet has been reached without striking ground water, but about 1½ miles west of this settlement there are pump wells 30 to 40 feet deep and shallow wells are also found between Hamiltons Fort and Kanarraville. There is a dug well only 12 feet deep at Bower's (NW. ¼ sec. 3, T. 36 S., R. 12 W.), where the altitude is about the same as at Thorley's flowing wells, and there was formerly a good well with the same depth at the Church ranch (N. ½ sec. 20, T. 35 S., R. 12 W.).

IRRIGATION WITH GROUND WATER.

Both the north basin and the south basin of the valley have possibilities of further development of the water in the unconsolidated deposits.

The recent success in prospecting for flows in Parowan Valley has revived interest in similar prospecting in Rush Lake Valley, and it is likely that before this paper appears considerable drilling will have been done. Although some irrigation could be accomplished with flowing well water, there is no indication that any extensive tracts could be reclaimed in this manner, because in the areas where flowing wells can be expected the soil is for the most part swampy and alkaline.

If wells of large diameter, several hundred feet deep, were widely scattered over those parts of the valley which have shallow ground water, but which are not swampy or burdened with alkali, and if pumps were applied to these wells, enough water could be recovered to bring hundreds of acres under irrigation. The construction of wells of this type is discussed on pages 59–64. If the water power

of the streams were developed, the pumping could be done at comparatively small cost, but even by the use of gasoline, producer-gas, or a proper type of steam engines pumping for irrigation can probably, with efficient management, be made profitable. Before installing pumping plants the precautions given on pages 49–53 should be observed.

CULINARY SUPPLIES.

At Cedar City, Hamiltons Fort, and Kanarraville the water from the mountain streams which furnish the irrigation supplies has up to the present time been used for drinking and culinary purposes. At Cedar City the water has been brought into the city through wooden mains; in the other two settlements it is drawn from the open ditches. At Cedar City steps have recently been taken to install a pipe line leading from a mountain spring, and at Kanarraville a similar project is under consideration. At Enoch the culinary supply is derived from springs and wells. The sanitary aspects of water supplies are discussed on pages 53–55.

ESCALANTE DESERT.

PHYSIOGRAPHY AND GEOLOGY.

Escalante Desert is an extensive plain surrounded by mountains, most of which are only moderately high. (Pl. II.) The rocks that constitute the mountains differ widely in character, age, and structure, but these differences have so little relation to the occurrence of ground water in the desert that they need not be discussed here. To a large extent the sedimentary formations are covered with volcanic rocks of Tertiary age.

When Lake Bonneville stood near its highest level Escalante Desert was occupied by a large but shallow bay of that lake (fig. 2), as is proved by the ancient shore features, which are distinct although not as impressive as in some localities. The monotonously flat surface of this desert, like that of Sevier Desert and Great Salt Lake Desert, is typical of ancient lake topography.

The desert is underlain by unconsolidated sediments derived from the rock waste of the surrounding mountains. In part these sediments were deposited by the streams; in part they were carried into the ancient lake and were allowed to settle quietly at the bottom of this lake. The lake-formed deposits in the interior of the desert probably consist largely of fine-grained sediments that will not furnish much water, but coarse materials that will yield their water freely are to be expected near the mouths of the principal canyons. The well sections given in succeeding paragraphs throw some light on the character of the unconsolidated beds.

RAINFALL.

In the following table are given the United States Weather Bureau records of precipitation in this region. At Modena the lightest annual precipitation since 1901, inclusive, was 5.09 inches, and the heaviest 16.62 inches, while the average for eight years is 11.50 inches. By reference to figure 4 it will be seen that the seasonal distribution of the rainfall is here somewhat different from that at the stations in Juab and Millard counties, the spring rainfall being less and the late summer rainfall being greater. Recently dry farming has been undertaken on a large scale near the mouth of Pinto Creek.

Precipitation (in inches) in Escalante Desert.

Modena.

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1901	0.43	3.63	0.06	0.68	0.65	0.32	1.33	1.17	0.06	0.78	0.01	0.12	9.24
1902	.33	.32	.54	.13	.19	.02	Tr.	1.58	.76	.04	.89	.29	5.09
1903	.12	.85	.74	.61	.55	.13	.14	.92	1.48	1.39	.00	.00	6.93
1904	.20	1.01	.98	.02	1.55	.11	.69	1.52	2.02	.50	.00	.23	9.83
1905	.86	1.79	2.09	1.05	.72	Tr.	.81	1.71	1.26	1.00	.90	.20	12.39
1906	.67	.47	3.22	2.91	1.31	.00	2.30	3.40	.91	.34	1.40	2.13	19.06
1907	1.63	.73	2.23	.51	1.71	.50	2.46	.77	.09	1.71	.12	.34	12.80
1908	1.62	1.47	1.10	.76	1.50	.37	2.76	2.76	1.64	1.76	.03	.85	16.62
Average	.73	1.28	1.37	.83	1.02	.18	1.31	1.73	1.03	.94	.42	.52	11.50

Near Enterprise.

1907	3.27	1 66	3.00	0.96	1.52	0.64	.....	.....	.....	.....	.....	0.10	.....
1908	2.53	2.56	1.09	1.56	1.37	.03	0.70	2.43	1.22	2.45	0.30	.73	16.97

Pinto.

1897	.....	3.05	4.11	0.78	0.52	0.05	0.90	0.89	2.17	3.76	0.40	1.16	.....
1898	1.28	.68	1.33	.39	2.30	.25	.07	.60	.00	.00	.11	.11	7.12
1899	.25	.35	2.17	.40	.58	.77	.05	1.06	.00	1.75	.67	.49	8.54
1900	.38	.27	.34	2.31	.65	.25	.13	.08	1.32	.77	3.16	.05	9.71
1901	1.72	2.74	.23	.85	.85	.45	.80	5.07	.00	1.43	.39	.57	15.10
1902	.61	.95	2.66	.25	.19	Tr.	.01	1.71	.20	.93	3.09	.70	11.30
1903	.93	1.06	1.57	1.30	.80	.17	Tr.	1.74	1.37	1.75	.00	.21	10.40
1904	.80	1.91	1.72	.44	1.90	.....	3.25	1.97	.99	.91	.00	.17	.....
1905	.64	1.88	2.28	1.48	2.09	.00	1.41	1.83	4.82	.77	1.67	.08	18.95
1906	2.72	1.52	6.45	2.15	.93	.17	1.64	2.82	1.82	.10	2.43	2.85	25.60
1907	2.63	2.00	2.92	.....	1.84	.62	2.14	.....	.....	3.09	.....	.....	.....
1908	1.20	2.40	1.59	2.10	.95	.09	2.15	3.45	2.53	2.24	.25	.90	19.85

Lund.

1901	0.15	1.73	Tr.	.....	.....	.....	.....	0.28	.....	.....	.....	0.05	.....
1902	.24	.05	.53	Tr.	Tr.	.....	.....	.....	.....	.....	.....	.....	.....
1903	.25	1.20	1.20	0.94	0.89	0.08	Tr.	2.70	0.50	1.60	0.00	Tr	9.36

SOIL.

The native vegetation shows that there are important differences in the character of the soil in different parts of the desert. On the bench lands along the borders sagebrush is found, but on much of the

low flat, where the ground water is near the surface and the soil contains alkali, greasewood and salt brush predominate.

In order to investigate the feasibility of irrigating with ground water in a low area where the water rises nearly or quite to the surface, samples of soil were obtained from two localities in this area, and these samples were analyzed by the United States Bureau of Soils. One set of samples was taken on the flat a short distance south of the station house at Lund, where water was struck at the depth of 6 feet; the other set was taken near Webster's flowing well, a short distance west of the Table Buttes, where water was struck at the depth of 4 feet. In both localities greasewood and salt brush were present, and in both the analyses show a soil that is high in alkali.

Analyses of soil at Lund, Utah.

Depth within which soil was taken.	Soluble solids (alkalies). Per cent of total material.	Predominating salts in order named.
Feet.		
1	2.1	Sulphates and chlorides.
2	2.1	Do.
3	2.5	Do.
4	2.1	Chlorides and sulphates.
5	2.2	Sulphates and chlorides.
6	2.7	Do.

Analyses of soil near Webster's flowing well, Escalante Desert, Utah.

Depth within which soil was taken.	Soluble solids (alkalies). Per cent of total material.	Predominating salts, in order named.
Feet.		
1	1.8	Sulphates and chlorides.
2	2.8	Do.
3	.8	Chlorides and bicarbonates.
4	.4	Bicarbonates and sulphates.

STREAMS.

Because of the general aridity and the low altitude of most of the surrounding mountains, few streams reach Escalante Desert. Aside from Iron Springs Creek, the only permanent streams in the basin rise in the relatively high mountains to the south. (See Pl. II.)

The most westerly of these streams is Shoal Creek, which emerges at Enterprise, in Washington County, and furnishes considerable

water for irrigation in that vicinity. Twelve miles up this stream there is a partly completed reservoir in which the flood waters will be stored, thus adding greatly to the available supply. Formerly the water was used at Hebron, which is farther upstream than Enterprise. Spring Creek is a much smaller stream that rises east of Shoal Creek, but also emerges from the mountains in the vicinity of Enterprise.

Meadow Creek is next east of Spring Creek. Formerly it furnished irrigation water for a small settlement at Hamblin, which is located in a meadow in the mountains, but some years ago heavy spring floods cut a deep gully through this meadow and thus robbed it of most of its water supply. At present the water of the creek is used at the Holtz ranch, which is located at the mouth of the canyon.

Farthest east are Pinto and Little Pinto creeks, which unite and flow out upon the desert at what is called the "Castle," or the "Mouth of Pinto." Much of the water of Pinto Creek is used at a settlement called Pinto, which, like Hebron and Hamblin, is situated in the mountains, but important water rights have also been established below the Castle.

SPRINGS.

The low mountains west of the railroad contain many small springs which are valuable chiefly as supplies for live stock on the range. Only a few of the best known of these springs are shown in Plate II. Many of them are seeps from the disintegrated igneous rock.

Sulphur Spring is about $1\frac{1}{4}$ miles west-northwest of Lund and at about the same level. It is situated at the base of a low alluvial slope bordering the western mountains. The small amount of water that it yields is used only as a supply for live stock.

The Desert Springs are situated northwest of Modena and other small springs occur farther up the canyon in which they are found. The locomotive and culinary supplies at Modena come from a number of large dug wells about $4\frac{1}{2}$ miles northwest of the village, the water being conducted to the village, by gravity, through a 6-inch pipe line. At Gold Springs and Stateline, two small mining camps northwest of Modena, the water supplies are derived chiefly from springs.

Iron Springs, which have been described in the section on Rush Lake Valley (p. 145), but whose water drains into Escalante Desert, are the largest springs in the Iron Mountains. Other springs in these mountains and within this drainage basin are Antelope Springs, in sec. 4, T. 35 S., R. 14 W., and Sand Springs, between this point and the Mouth of Pinto. Numerous springs are found in the mountainous area south of the desert.

FLOWING WELLS.

Webster's well.—A flowing well belonging to John Webster is located in the interior of Escalante Desert, along the road leading from the Mouth of Pinto to Lund, a short distance west of Table Buttes, which form a well-known landmark in this region. (Pl. II.) The surrounding country lies low, is flat except for minor irregularities that have been developed by wind erosion, and in wet seasons is partly submerged by accumulating storm waters. The well is $1\frac{1}{2}$ inches in diameter, is reported to be 160 feet deep, and yields several gallons of water per minute by natural flow. The water is good to the taste; it was found to contain only 29 parts per million of chlorine but it gave a slight reaction for normal carbonates.

Wells at Sulphur Springs and Lund.—A small flowing well in the vicinity of the Sulphur Springs is said to be 280 feet deep but little reliable data in regard to it could be procured. In his report on the water resources of Beaver County, Lee states that in the 585-foot railroad well at Lund flowing water was struck at 5 horizons,[1] but from the best information available it appears that these flows took place in a pit and that the water never rose higher than within one or two feet of the natural surface.

NONFLOWING WELLS.

Railroad wells at Lund.—The old railroad well at Lund is said to be 4 inches in diameter and several hundred feet deep, but reliable information in regard to it is lacking. Originally the water rose within $1\frac{1}{2}$ feet of the surface, but now it remains at a depth of about 8 feet.

The new well, completed in 1903, was carried to a depth of 585 feet. The casing is 12 inches in diameter at the top, but is reduced to 10, 8, and finally 6 inches. As in the old well, the water at first rose within $1\frac{1}{2}$ or 2 feet of the surface, but has since retreated to a level about 8 feet below the surface. Mr. Lee states that when this well is pumped it yields 100 gallons per minute with a temporary depression of the water surface of less than 20 feet. The following section of the new well, taken from Mr. Lee's report, shows that the sediments underlying Lund are predominantly fine-grained, but that a few beds of gravel and coarse water-bearing sand exist.

[1] Lee, W. T., Water resources of Beaver Valley, Utah: Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 31.

Section of the railroad well at Lund, Utah.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand	2	2
Clay	4	6
Gravel (small flow)	6	12
Coarse gravel	4	16
Hardpan and clay	49	65
Quicksand	4	69
Blue clay	80	149
Sand	4	153
Red clay	12	165
Blue clay	159	324
Red rock	6	330
Blue clay	70	400
Quicksand	20	420
Green shale rock	10	430
Clay and sand	10	440
Sand (small flow)	3	443
Blue clay	11	454
Clay and sand	8	462
Sand (large flow)	13	475
Clay	3	478
Sand	6	484
Red clay	2	486
Very fine sand	8	494
Red clay	10	504
Dark clay	4	508
Blue clay	14	522
Very fine sand	3	525
Blue clay	2	527
Fine sand (small flow)	3	530
Brown clay	19	549
Sand	1	550
Brown clay	23	573
Coarse sand	10	583
Coarse gravel (large flow)	2	585
Blue clay	.....	.....

The water is only moderately mineralized, as is shown by the following analysis made for the railroad company in January, 1905:

Analysis of water from the new railroad well at Lund, Utah.

[Parts per million.[1] Analyst, Herman Harms.]

Total solids	486
Silica (SiO_2)	64
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	4
Calcium carbonate ($CaCO_3$)	47
Calcium sulphate ($CaSO_4$)	33
Magnesium carbonate ($MgCO_3$)	63
Sodium chloride ($NaCl$)	116
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile and organic matter, and loss	159

Railroad well at Beryl.—In the railroad well at Beryl, which is 13 inches in diameter and 208 feet deep, water was found at depths of 23 feet, 180 feet, and 203 feet. The well as finished draws from the 203-foot bed, from which the water rises within 19 feet of the surface. During a pumping test of 24 hours the well is said to have yielded 183 gallons per minute. A 4-foot hole sunk to the depth of 23 feet yielded 20 gallons per minute.

[1] Reported by the chemist in grains per gallon.

Section of the railroad well at Beryl, Utah.[1]

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	8	8
Clay and gravel	8	16
Gravel (water-bearing)	7	23
Gravel and clay	15	38
Clay	80	118
Clay and gravel	57	175
Gravel (water-bearing)	5	180
Clay	20	200
Sand (water-bearing)	3	203
Clay	5	208

Lee, W. T., Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 31.

The water from this well, like that from the Lund well, is used in the boilers of the locomotives. As shown in the following analyses, it contains only moderate amounts of the mineral substances commonly found in ground waters.

Analyses of water from the railroad well at Beryl, Utah.

[Parts per million.[1] Analyst, Herman Harms.]

	Sample from depth of 25 feet [2]	Sample from bottom.[3]
Total solids	492	344
Silica (SiO_2)	92	61
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	4	2
Calcium carbonate ($CaCO_3$)	72	74
Calcium sulphate ($CaSO_4$)	49	41
Magnesium carbonate ($MgCO_3$)	37	42
Sodium chloride (NaCl)	86	70
Magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), volatile, organic, and loss.	152	49

[1] Reported by the chemist in grains per gallon.
[2] Sample collected Aug. 27, 1905.
[3] Lee, W. T., Water-Supply Paper U. S. Geol. Survey No. 217, 1908, p. 51.

State test well near Enterprise.—A test well was sunk by the State at a point a few rods north of the boundary between Iron and Washington Counties and near the line between Rs. 16 and 17 W. As far as could be ascertained no record was kept and the only information was that furnished from memory by the driller, Mr. Halterman, of Parowan. He states that the materials penetrated by the drill consisted of gravel and other unconsolidated sediments for the first 300 feet, and of red rock from this depth to about 700 feet, where hard rock was struck and the drilling was stopped. He states also that water was found at the depth of 40 feet and at various horizons below this level, and that the water from the unconsolidated sediments rose within about 40 feet of the top of the well, but that the water from the rock remained 90 feet below the surface. It appears that

no tests were made of the quantity or quality of the water and that the well has remained practically unused.

Well of the New Castle Reclamation Co.—The New Castle Reclamation Co. has a dug well, 86 feet deep, situated in the NE. ¼ sec. 7, T. 36 S., R. 15 W., several miles northwest of the Mouth of Pinto. In October, 1908, the water in this well stood 81 feet below the surface, was yielded freely, and was considered to be of good quality.

Section of the New Castle Reclamation Co.'s well.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay loam	18	18
Gravel	8	26
Clay and sand alternating	14	40
Gravel	8	48
Clay	27	75
Hard clay	1½	76½
Black gravelly sand	2½	79
Dense clay	1	80
Black sand (water which did not rise)	1	81
Dense clay	1	82
Black sand (water which rose to level of first water-bearing bed)	1	83
Clay	1	84
Sand (water which rose to level of first water-bearing bed), entered	2	86

Other wells.—The well just described is typical of more than a score of wells that have been dug at different points in the desert, chiefly for the purpose of watering sheep or other live stock. Practically all of these wells are less than 100 feet deep because the holes that were dug where the ground-water table is more than this distance below the surface were generally abandoned before the requisite depth was reached. Most of the dug wells yield water of fairly good quality and in ample amounts for stock purposes, but there are exceptions both as to quality and quantity.

DEPTH TO GROUND WATER.

Vicinity of Lund.—The depth to which it is necessary to sink a well in order to reach the ground-water table depends largely on the altitude of the surface. At Lund the water table nearly coincides with the surface, and this condition prevails west of Lund to Sulphur Springs, north, northeast, east, and southeast of Lund for some miles, and south of Lund to beyond Webster's flowing well. With certain interruptions, it also prevails from Webster's flowing well to T. 35 S., R. 16 W., where water is obtained at very shallow depths.

Between Lund and Modena.—Along the railroad southwestward from Lund the surface gradually rises, but water can be obtained at moderate depths between Lund and Beryl (see p. 155) and probably between Beryl and a point some distance southwest of Morton, beyond which the railroad has a steeper gradient and the depth to water

is greater. In going from the railroad toward the western mountains the depth to water also increases, and near the mountains it may be impracticable to get wells.

Southeast of Modena.—East and southeast of Modena there is an extensive area of fertile land that lies somewhat above the desert flat and is partly encircled by low rocky ridges. Except near the ridges, wells can probably be obtained in this area at reasonable depths, but flows are not to be expected.

North of Enterprise.—Water can probably be obtained at moderate depths on a large part of the bench that lies east of the ridge extending northward from Enterprise. On the low ground at the foot of this bench there are some indications that flows could be obtained.

Vicinity of New Castle.—An alluvial slope extends along the border of the mountains from Enterprise to the vicinity of New Castle and from New Castle to the north end of the Iron Mountains. This belt is especially wide in the reentrant occupied by the alluvial fan of Pinto Creek. A number of wells already sunk in the region give some indications as to the position of the water table. Thus in the NE. ¼ sec. 7, T. 36 S., R. 15 W., ground water was found at the depth of 80 feet; near the middle of the line between T. 36 S. and T. 35 S., in R. 15 W., it was found at about the same depth; and on sec. 31, T. 35 S., R. 15 W., it was found at 25 or 30 feet.

Eastern part of the desert.—In the low-lying areas of the eastern part of the desert the water table can be reached by sinking to moderate depths but on the higher benches the distance to water is no doubt great. The Iron Mountains are projected northward in two ranges, one of which extends to Antelope Springs, the other to Iron Springs and beyond. (See Pl. II.) Between these two ranges there is a wide reentrant which occupies a township or more of land and consists of a large alluvial slope in the shape of an amphitheater. In this reentrant plain, especially at the higher levels, the prospects for obtaining water are poor.

QUALITY OF GROUND WATER.

In the railroad wells at Lund and Beryl water of satisfactory quality was found, as is shown by the analyses given on pages 154–155. These analyses and less definite data in regard to other wells indicate that the water in the beds of sand and gravel underlying Escalante Desert is in general not so highly mineralized as to be unfit for culinary use or irrigation. An exception is formed by some of the dug wells in the shallow-water tracts, the water from which, like the soil in the same tracts, may be heavily charged with mineral salts.

USE OF GROUND WATER.

The ground water of this region is used for locomotive, live-stock, and culinary supplies. Relatively large amounts of fairly good water are required for locomotive supplies, and consequently the most thorough and valuable explorations for ground water in this region have been made by the railroad company. As can be seen from the descriptions of the wells at Lund, Beryl, and Modena, the efforts to secure satisfactory railroad supplies were, on the whole, successful in this region, in which respect Escalante Desert contrasts favorably with the lower part of Sevier Desert and Lower Beaver Valley. Most of the wells in this desert have been dug for the purpose of procuring water for live stock, and many springs have been developed in the western mountains for the same purpose. These watering places have made the range accessible and have thereby added greatly to its value. Recently dry farming has been undertaken and accordingly a new demand for water has been created.

No serious efforts have yet been made to use the ground water for irrigation. Flowing wells are not likely to be of much value for this purpose because they are obtained only in low areas where the soil is impregnated with alkali, and even in these areas the water is under so little pressure that it would be difficult to obtain large enough supplies to be of consequence in irrigation. On land which lies somewhat higher than the alkali desert flats and has better soil considerable irrigation water could in the aggregate be recovered by pumping from moderate depths, but the amount that could be recovered in any one locality is probably not great, and it is doubtful whether even in the more favored tracts pumping for irrigation would be practicable.

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TOOELE CO
JUAB CO

BOUNDARY
LINE

JUAB CO
MILLARD CO

BOUNDARY
LINE

Rocky Springs Peak

Indian Village

Bald Mtn

Haystack Peak

Queen of Sheba Mine

Callao

Boyd Station

Hot Springs

Big Spring

Salt Well

Utah Mine

Thomas Ranch

Fish Springs

Fish Spring

Spring

Salt Spring

To Ajax

Thomas Spring

Cane Spring

Fish Springs

Topaz Mtn

Sand Pass

Granite Mtn

The Chimneys

Bishops Ranch

Trout Creek

To Pleasant Valley

Grandy

Foutes Ranch

Bishop Spring

Indian Pass

Smithville

Kell Spring

Knoll Spring

Simonsons Ranch

Conger Ranch

To Garrison

Willow Spring

Tule Spr

South Tule Spring

Cowboy Pass

Coyote Spring

Antelope Mtn

Swasey Pk

Wheeler Amphitheater

Antelope Spring

Swasey Spring

Howell Peak

Tatow Knob

Marjum Pass

Twin Buttes

Rainbow Valley

Wenks Canyon

Orr Ridge

Granite Canyon

Notch Peak

Soap Hollow

To Deseret

Little Drum Mountains

Drum Mtns

Drum Low Pt

Mine

Whirlwind Valley

Sevier River

Sevier Lake

To Garrison

Deep Creek Range

Fish Springs Flat

Thomas Range

Fish Springs Range

Confusion Range

Conger Range

Long Ridge

Valley

Creek

Canyon

Wash

Spring

R 19 W R 18 W R 17 W R 16 W R 15 W R 14 W R 13 W R 12 W R 11 W R 10 W

T 14 S. T 15 S. T 16 S. T 17 S. T. 18 S. T 19 S T 20 S. T 21 S

R B Marshall Chief Geographer

TOPOGRAPHIC MAP OF FISH SPRINGS QUADRANGLE, UTAH

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 278

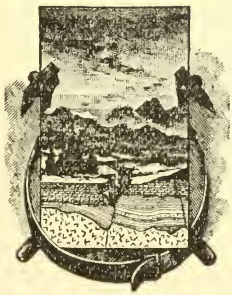
WATER RESOURCES

OF

ANTELOPE VALLEY, CALIFORNIA

BY

HARRY R. JOHNSON



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WATER RESOURCES OF THE ANTELOPE VALLEY, CALIFORNIA.

By Harry R. Johnson.

INTRODUCTION.

Before the problem of making productive the waste spaces of the great West had been attacked with the vigor which during the last 20 years has wrought so great a change in portions of the western States and Territories, the term "desert," carrying a picture of utter desolation—of miles of treeless sand or, at best, of waterless sagebrush plains and barren mountains—was applied to great stretches of country having unrecognized potentialities, so that the idea became fixed in the public mind that such areas were practically worthless. This idea was reflected in the maps of the period, on which vast areas having vaguely defined limits were labeled "desert." Thus an extensive region in southeastern California lying east of the southern end of the Sierra Nevada and of the Tehachapi Range and north of the San Gabriel and San Bernardino ranges became known as the Mohave Desert. This great area, however, lying between the more favored coastal region south of the Sierra Madre and the agricultural and mining districts of the San Joaquin Valley, Sierra Nevada, and Colorado River, became in time the highway of overland travel, and its true character gradually became better known. Potable underground waters were discovered, the desert's agricultural value was recognized, settlement was begun, and the available surface water supplies were developed. With the growth of fixed population, distinctive names were applied to different parts of what was originally known merely as "the desert." Thus an area extending along the north side of the San Gabriel and San Bernardino ranges in the southwestern part of the region became known as Antelope Valley. At first the extent of this valley was not clearly outlined, but during recent years its limits have become more strictly defined. In like manner, the term "Mohave Valley" is applied even to-day, rather elastically, to the broad alluvial region on both sides of Mohave River from the margin of the San Bernardino Range northward.

The rapid development of southern California in the early eighties, soon after the completion of the Santa Fe Railroad, brought a large number of eastern people to the region. Land values, already high, soon became greatly inflated, and realty speculations passed all reasonable bounds. Partly as a reaction from this condition in the Los Angeles region and partly as an expression of the promoters' abundant confidence, Antelope Valley, with its large area of cheap lands, was invaded by intending settlers, most of whom knew little or nothing of the peculiar limitations of development in arid California.

At this time and for a few years afterward Antelope Valley was developed rapidly rather than wisely. Of the towns then established, several now exist only in memory. Of Hispaniola, in T. 9 N., R. 16 W., but a few posts bearing street names remain; Tierra Bonita, a few miles east of Palmdale, has vanished; the site of Almondale, farther south, with its complex system of avenues and a former population of over 200 people, is marked now by a dilapidated brick house and barn. Many ranch houses erected here and there in the valley at that time have been deserted for years.

Most of these early settlers were victims of the promoter's wiles, of their own lack of caution and foresight, and of their general ignorance of local features and conditions, especially of water supply and climate. In the settlements near the west end of the valley it was generally believed that the winter rainfall would be sufficient for crops and pasturage, and that water for domestic uses could be had only a few feet below the ground surface, as in the eastern lands from which most of the settlers had come. When it was found that the normal winter rainfall was at most 6 or 8 inches, and that around the margin of the valley water obtainable by wells lay in many places 100 feet or more below the valley floor, farming without irrigation was admitted to be impossible and one by one the homesteads were abandoned.

Such localities as Almondale, or old Palmdale, which depended for their prosperity on water brought from Rock and Little Rock creeks, have a similar history. Thousands of dollars were spent in improvements, and crops were planted and even brought to maturity before it was realized that the costly systems had been built without definite knowledge of the supply of available water, which proved totally inadequate when the dry seasons came.

These disastrous and unnecessary failures stopped for a time all growth in the valley, but development has lately taken a more satisfactory direction. With a frank recognition of the agricultural and climatic limitations of the region as compared with other parts of California has come a realization of the value of the artesian waters which, though long known to exist, had previously been usefully employed in only a few localities.

U. S GEOLOGICAL SURVEY

SKETCH MAP OF PART OF SOUTHERN CALIFORNIA, SHOWING POSITION OF ANTELOPE VALLEY

THE NORRIS PETERS WASHINGTON D C

Even now comparatively little of the water thus available is used to its fullest extent, and the most important problem confronting the settler in and near the flowing-well area of the valley is not where the water can be found, but how it shall be used to the best advantage.

The most hopeful phase of present utilization of water in the region is the increasing use of pumping plants, which makes possible the cultivation of lands around the margin of the artesian areas, where the soils are as a rule less alkaline than those in the lower part of the valley.

During this later period of development the settlements that survived the collapse of the earlier boom, as well as those of more recent establishment, have been benefited by the increased agricultural output. Of these settlements, Lancaster, on the Southern Pacific Railroad, a town of about 400 population, is the most important, for the most notable increase in the use of pumped waters for irrigation has taken place near that town. Other settlements are Rosamond, near the north margin of the valley; Palmdale, about 10 miles south of Lancaster; Little Rock, in a fruit-growing section at the mouth of Little Rock Canyon; Willow Springs, an oasis in the dry plains, some miles west of Rosamond; Fairmont, Del Sur, Neenach, and Manzana, along the road between Lancaster and Gorman station; North Portal, the temporary headquarters for operations at the north end of the Elizabeth Lake tunnel, under construction as a part of the new Los Angeles water-supply system; and Redman ranch, the headquarters of a newly established colony in the eastern part of the valley.

The investigation of ground-water supplies in Antelope Valley, reported on herein, is only an extension of work carried on during the last 10 years by the United States Geological Survey—work that has comprised rather detailed studies of underground water in the part of southern California south of the San Gabriel and San Bernardino ranges and has resulted in the publication of a number of reports.[1] (See Pl. I.)

The maps that accompany this report are necessarily of reconnaissance nature and have been prepared from various official and private sources supplemented by notes made in the field by the author. Where insufficient data were available, the locations of wells and other cultural features may have been incorrectly made, but it is believed that in general the maps are fairly trustworthy.

The usefulness of such a report as is here presented depends very largely on the information and aid given by the people of the region under investigation, and the writer desires to express his indebtedness to the many persons who have assisted him in preparing his paper.

[1] Water-Supply Papers U. S. Geol. Survey Nos. 59, 60, 112, 137, 138, 139, 142, 219, 225.

TOPOGRAPHY.

Antelope Valley is in the southwestern part of the Mohave Desert, lying between the rugged mass of the San Gabriel and the northwest end of the San Bernardino ranges on the south and the Tehachapi Range on the west. The Tehachapi and San Gabriel ranges present bold and in many places precipitous faces toward the desert, but from a point near Palmdale northwestward the subsidiary hills known as Portal Ridge help to lessen the contrast between the steep San Gabriel Range and the flat Antelope Valley.

The lowest part of this depression, lying at an elevation of about 2,300 feet, is occupied by Rosamond, Buckhorn, and Rogers dry lakes, and the surface of the valley slopes toward this area with a grade that decreases with distance from the mountains. The margin of the valley lands ranges in elevation from 2,600 feet along the south foot of the Rosamond Buttes to more than 4,000 feet on the Tehachapi flanks. The valley is an undulating brush-covered plain except for barren steep-sided buttes and ridges which rise islandlike above the level land and which are typified by the Sand Hills just southwest of Cottonwood Creek Wash; by Antelope Buttes, near Fairmont; by Little Buttes, about halfway across the valley between Del Sur and Willow Springs; by Quartz Hill, about 5 miles southwest of Lancaster; by a butte at the northwest end of Buckhorn dry lake; and, in the eastern part of the valley, by many sand dunes.

The irregular distribution of some of the marginal buttes has produced corresponding irregularities in the outline of the valley lands, so that in many places tongues of alluvial material extend away from the main depression in among the buttes for a considerable distance. Such a tongue is the open stretch or pass of irregular width between Antelope Valley and Mohave Valley, along the flank of the San Gabriel Range.

DRAINAGE.

GENERAL FEATURES.

The outline of Antelope Valley is determined on the south and west respectively by the position of the crests of the San Gabriel and Tehachapi Ranges and is fairly definite, for these ranges have considerable elevation and their summit lines are continuous and clearly marked. Toward the north and east, however, the position of the divides is at present less certainly known. Between the edge of the Tehachapi Range near Cottonwood Creek and the west end of Rosamond Buttes near Willow Springs, there is a stretch of detrital material 8 to 10 miles wide which extends northeastward along the Tehachapi flank. This area was visited only in the neighborhood of Willow Springs, but it is believed to be a part of the drainage basin

of Antelope Valley, although the streams at its northeast end may possibly drain toward the town of Mohave and out toward the northeast. The somewhat similar arm of the valley extending from Palmdale southeastward along the flank of the San Gabriel Range for a number of miles probably marks the divide between Mohave River and the Antelope Valley drainage basin. Thus, though it is known that practically all the waters of Rock and Little Rock creeks, except the parts lost by evaporation, find their way eventually into the Antelope Valley basin, it is not so certain that the streams farther east, which debouch upon the alluvium from the San Gabriel Range, ever reach Antelope Valley.

The volume of these more easterly streams is, however, unimportant, and as they flow northward they distribute their waters among the many buttes so that their channels can not be continuously traced. Undoubtedly Turner dry lake ultimately receives the discharge of some of these streams, and others, as the Oro Grande Wash, may swing toward the east and find their way into the basin of Mohave River.

It is believed that for the purposes of this report a line drawn from a point about 6 miles east of Tilghman northward through Black Butte and then approximately along the county line somewhat east of north toward Haystack Butte may be considered the divide between the Antelope Valley drainage basin and that of Mohave River.

Although in its general features Antelope Valley resembles the Mohave Desert, its position at the immediate base of the Tehachapi and Sierra Madre ranges modifies favorably the amount and quality of the waters which reach the lowlands. Some of the streams flowing from these higher ranges are perennial and all supply better water than the smaller streams that flow from the buttes of the desert proper. The two ranges are so high that their snow cover often remains until midsummer and maintains a continuous though gradually diminishing flow of water. On the other hand, the region is prevented by its position on the landward side of the ranges from receiving the benefit of the heavy winter precipitation and consequent heavy run-off of the more favored southern and western slopes.

In general the streams of Antelope Valley flow at right angles to the trend of the mountains in which they originate; most of these streams converge toward Oban, and thence, though their channels are less clearly defined, sweep toward the northeast and empty into the Rosamond dry lake, or its extensions, the Buckhorn and Rogers dry lakes.

The drainage lines north and east of the Rogers dry lake are unknown to the writer; most of the maps of the Mohave Desert region so far published are much generalized and they are not consistent, but a study of several of them indicates that a depression may

extend from the north end of the Rogers dry lake northeastward and eastward toward the Barstow region and about parallel with the Santa Fe Railway. On the other hand, the Rogers dry lake may be completely inclosed on the north by metamorphic and granitic marginal rocks. (See pp. 22–24.)

Probably the most striking feature of drainage in Antelope Valley, as elsewhere in the arid West, is the sudden diminution in flow of all the streams as they enter the valley itself. Thus, except during periods of heavy precipitation, the streams without exception sink beneath the gravels of the valley at a distance of not more than 3 miles from the mouths of their canyons. When the region was visited, in the early winter, many of these streams were flowing quite heavily, but even at this time of the year no flowing surface water was found in the valley below an elevation of 2,500 feet, except what came from artesian wells and springs.

STREAMS.

None of the streams in the valley are large and only a few are worthy of mention. Those of the northern slope of the San Gabriel Range and the southeast slope of the Tehachapi are all short, with the exception of a few which have worked their way back far enough into the ranges to become important as water carriers. Of these Rock, Little Rock, and Amargosa creeks are the more important.

The main fork of Rock Creek rises in the rugged region north of North Baldy, at an elevation of 6,500 feet above sea level, and the uppermost tributaries of its south branch, which drains the region immediately north of Mount Islop, head at an elevation of fully 8,000 feet. The creek flows northwestward past Shoemaker's ranch to the northwest corner of T. 4 N., R. 9 W., where it turns northward to the gravelly margin of Antelope Valley. Here it breaks into several distributaries which diverge from the apex of the alluvial fan built up by the stream itself. The more or less constant flow of Rock Creek is utilized by irrigation canals that extend for some distance east and west from the mouth of the canyon. (See pp. 33–34.)

Little Rock Creek, which rises in the high granitic mountain country in T. 3 N., R. 10 W., flows northwestward and enters Antelope Valley near Little Rock, in the northeast quarter of T. 5 N., R. 11 W. The channel of this creek in Antelope Valley is better preserved than that of any of the other streams and it is traceable almost to the vicinity of C. N. Reid's ranch, nearly 7 miles east of Lancaster. Here, however, the channel begins to lose its character and is not easily followed farther toward the Rosamond dry lake. The waters of this stream are used to irrigate lands adjacent to the settlement of Little Rock.

Amargosa Creek, which enters Antelope Valley about 3 miles west of Palmdale, is the only stream with even moderate flow between Little Rock Creek and the extreme west end of Antelope Valley. It was not visited, but it is understood to possess little value as a source of surface irrigation waters, as it heads somewhat below the snow line in the San Gabriels and its flow is therefore inconstant.

A number of streams which, though draining rather small areas, carry considerable water, rise at the west end of Antelope Valley, between the junction of the Tehachapi and San Gabriel ranges. These streams are fed by copious springs which are particularly numerous at the southwestern end of the Tehachapi Range near the foot of the steep slopes. The largest of these creeks is called the Little Cottonwood, and, at the time it was visited, it flowed as far east as the east line of sec. 1, T. 8 N., R. 17 W. No accurate measurements of any of these springs or creeks are available. The large spring at Liebre ranch flows 1,500 gallons per hour.

Between Little Cottonwood and Cottonwood creeks are Fish, Livsey, Tierra Seca, and Little Oak creeks, each less than 5 miles long, but a source of considerable water even in the summer time. It is stated that the drainage basins of these streams contain large springs which furnish much of the stream water that eventually finds its way into the gravels in this part of the Antelope Valley.

Cottonwood Creek, the most important stream flowing into Antelope Valley from the Tehachapi Range, rises at an elevation of over 6,000 feet above sea level at a point some 8 miles west of Knecht's ranch, which is practically at the apex of the great alluvial fan built by this stream below the mouth of its canyon. Since this fan was deposited, the erosional ability of the creek has been changed, either through uplift or climatic oscillations, so that it has carved a sharply defined gulch in its own fan. In the northeast corner of T. 9 N., R. 15 W., this gulch is a prominent feature, but farther down in its course the stream, previously confined within a single channel, begins to distribute itself over a later alluvial fan which was apparently built up out of the loose gravels removed from its older delta. This portion of the Cottonwood Creek drainage is known locally as the Cottonwood Wash. Measurements of the flow of Cottonwood Creek are not available, but at the time the creek was visited water was running freely almost to the old road crossing near the stone hut in sec. 2, T. 9 N., R. 15 W.

At the west end of Rosamond Buttes a sharply marked gulch extends from a point due north of and near Willow Springs. It is not known to just what drainage this gulch belongs, but it is probably a distributary of the stream which flows southward along the W. ½ of T. 10 N., R. 13 W. Other stream channels in the Rosamond Buttes are mere paths for storm waters.

LAKES.

Lakes and ponds, most of them intermittent in character, exist at a number of points in and near Antelope Valley.

The most permanent—Hughes and Elizabeth lakes—lie in depressions in an alluvial trough coinciding with the San Andreas fault zone. Elizabeth Lake receives the drainage of a small area in the surrounding hills and may be fed by springs. Its waters remain fairly fresh, however, for at the northwest end it overflows occasionally through a meandering channel into the smaller Hughes Lake, which in turn feeds the headwaters of a southward-flowing stream that is a part of the Santa Clara drainage.

Of somewhat similar character, except that they lie in completely inclosed depressions and are usually dry during part of the year, are Quail Lake, near the west end of Antelope Valley, and the Palmdale reservoir, which was a closed depression even before the present levee and dam construction was undertaken. The existence of these lakes depends entirely on peculiar structural conditions to be described later (pp. 20–22).

Intermittent lakes of another type are formed in the lowest portions of the broader alluvial basins by the addition of such flood waters from the surrounding drainage area as have not been absorbed en route by the gravels of the basin. In this arid region such waters, combined with those due to upward leakage, usually hold in solution considerable saline material, and on their evaporation leave the salts as an incrustation within and about the margin of the dry lakes. These lake or "playa" deposits are nearly level and form a smooth, hard surface which, as in the Rogers dry lake, extends for many miles. Except during the hardest storms the lakes rarely contain water, unless where the ground-water plane approaches sufficiently near the surface to produce small scattered pools and damp spots of alkali-charged waters. Several such lakes of minor importance occur southeast of Antelope Valley.

CLIMATE.

RAINFALL.

Climatologic data, except rainfall records, are meager for the Antelope Valley region. The records kept at Manzana, in the western part of the valley and at Palmdale, in the south-central portion, form a fair basis for judging the amount of precipitation in other sections of the valley. It is a general rule in the more arid inland parts of California that precipitation decreases with elevation. Hence it is probable that the rainfall in the vicinity of the Rosamond and Rogers dry lakes is somewhat less than at Manzana and Palmdale. Precipitation throughout this region occurs almost wholly

during the winter, the occasional summer storms being usually in the form of cloudbursts, during which several inches of rain may fall in a short time.[1] The available rainfall records are presented in the following tables:

Rainfall records for Antelope Valley region.

PALMDALE HEADWORKS.

[Elevation, 3,299 feet.]

Years.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Annual.
1896–97	0.25	1.35	0.32	1.42	0.43	0.98	3.78	3.71	1.31	0.04	0.32	0.00	13.91
1897–98	.03	1.57	T.	.86	.00	.14	2.38	.07	.90	.00	.21	.00	6.16
1898–99	.02	.05	.00	.00	T.	.87	1.00	.31	.97	.00	.00	.00	3.22
1899–1900	.00	.00	.00	1.28	.27	.32	.65	.00	.80	.57	.76	.00	4.65
1900–1901	.00	.00	.00	.20	1.79	.00	1.34	4.50	.38	.15	T.	.00	8.36
1901–2	.00	33	T.	.32	.04	.00	(a)	(a)	(a)	(a)	(a)	(a)	.....
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.26

PALMDALE.

[Elevation 2,657 feet.]

1901–2[a]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1902–3	(a)	(a)	(a)	(a)	(a)	(a)	0.36	0.65	2.58	2.00	0.00	T.	.....
1903–4	0.00	0.00	0.00	0.00	0.00	.....	.....	.....	.....	.....	.....	.....	.....

MANZANA.

[Elevation, 2,870 feet.]

1894–95	0.00	0.10	0.49	0.00	0.00	3.60	2.79	0.00	1.36	0.08	T.	0.00	8.42
1895–96	.00	.00	.00	.40	.48	.18	1.09	0.00	1.70	.63	T.	.00	4.48
1896–97	T.	1.04	.00	.61	.30	1.46	2.70	3.04	1.71	.04	0.01	T.	10.91
1897–98	T.	.28	.00	.21	T.	.14	1.70	.02	.47	.00	.25	.00	3.07
1898–99	.00	.00	T.	.00	T.	.50	1.15	T.	1.35	.04	.09	.04	3.17
1899–1900	.00	.00	.00	1.27	.71	.29	1.11	.10	.93	.42	.38	.00	5.21
1900–1901	.00	.08	.10	.09	2.55	.00	3.20	6.68	.25	.61	.12	.00	13.68
1901–2	.00	.65	T.	2.02	.20	T.	.67	1.52	1.14	.....	.....	T.	6.20
1902–3	.00	.00	.03	1.99	1.78	.....	.60	.96	3.02	3.46	.00	.....	11.84
1903–4[a]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.44

LITTLE BEAR VALLEY (SAN BERNARDINO MOUNTAINS).

[Elevation, 5,150 feet.]

1893–94	(a)	(a)	1.21	1.49	2.55	7.61	2.48	2.25	3.16	0.62	1.34	.12	22.83
1894–95	0.04	0.31	.52	.38	.00	20.12	15.27	2.01	8.82	1.31	.00	.00	48.78
1895–96	.00	.00	.00	.00	2.65	1.75	2.38	T.	4.21	1.72	.47	.00	13.18
1896–97	.00	.10	.00	2.30	1.38	1.98	5.16	11.74	10.17	.03	.15	.20	33.21
1897–98	.00	.00	.46	4.10	.76	1.20	3.80	1.38	2.49	.25	4.56	(a)	20.00
1898–99	.00	(a)	(a)	T.	.62	.74	(a)	(a)	(a)	(a)	(a)	(a)	.....
1899–1900	(a)	(a)	(a)	(a)	(a)	(a)	1.39	.43	3.42	3.11	4.63	(a)	.....
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	27.60

[a] No record.

[1] On Aug. 16, 1896, there was a cloud-burst at Harold station in which 5 inches of rain fell in two hours. Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, p. 403.

Rainfall records for Antelope Valley region—Continued.

BARSTOW.

[Elevation, 2,150 feet.]

Years.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Annual.
1890–91	.....	.....	.....	.....	.....	.....	0.00	2.47	T.	0.05	T.	0.00	[a] 2.52
1891–92	T.	0.06	0.08	0.00	T.	0.25	[b]	[b]	[b]	[b]	[b]	[b]	[a] .39
1892–93	[b]	[b]	[b]	[b]	[b]	[b]	.11	.27	0.77	.06	T.	.00	.....
1893–94	1.10	.00	.00	.22	T.	.72	.02	.21	.06	.00	0.22	T.	2.55
1894–95	T.	.34	.00	.00	.00	.92	1.06	.00	.20	.00	.00	.00	2.52
1895–96	[b]	[b]	.00	.00	T.	.00	.16	.00	.08	.00	.00	.00	.24
1896–97	.07	.87	.00	1.55	.25	.30	2.15	.65	.11	.00	.00	.00	5.95
1897–98	T.	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	.....
1898–99 [1]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1899–1900 [1]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1900–1901 [1]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1901–2 [1]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1902–3	[b]	[b]	[b]	[b]	[b]	[b]	.50	.55	1.00	.10	.00	T.	.....
1903–4	.00	T.	.50	.00	.00	.00	T.	.30	.10	.00	.00	.00	.90
1904–5	.40	T.	.00	.00	.00	T.	1.10	.50	3.50	.40	.00	.00	5.90
1905–6	.00	T.	.00	.00	.90	T.	.65	T.	.00	.25	.00	[b]	1.80
1906–7	[b]	[b]	[b]	[b]	2.00	T.	.....	.....	.....	.....	.....	.....	.....
Mean for 8 years	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.85

[a] Half-year record. [b] No record.

Monthly and annual mean precipitation at Mohave (elevation, 2,751 feet).

Years.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Annual.
1877–78	0.00	0.00	0.00	0.00	0.00	2.38	1.22	1.74	0.30	0.76	0.00	0.02	6.42
1878–79	.00	.10	.29	.00	.32	1.07	.62	.05	.60	.22	.00	.00	2.67
1879–80	.00	.00	.00	.00	.42	4.16	.40	.50	.71	.60	.00	.00	6.79
1880–81	.00	.00	.00	.00	.00	1.03	.00	.00	.06	.18	.00	.00	1.27
1881–82	.00	.00	.00	T.	T.	T.	.05	.58	.00	.00	.00	.00	.63
1882–83	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	T.	.00	T.
1883–84	.00	.00	.00	.10	.00	.25	1.77	5.69	2.17	.61	.00	1.05	11.64
1884–85	.00	.00	.00	.13	.31	1.59	.00	.06	.00	.61	.14	.00	2.84
1885–86	.71	.00	.00	.00	1.25	1.16	1.49	T.	1.22	.14	.00	T.	5.97
1886–87	T.	.00	.00	T.	.76	.08	T.	4.09	.00	.14	.00	.00	5.07
1887–88	.00	.00	.00	.95	.56	1.06	2.62	1.56	1.75	.00	.00	.00	8.50
1888–89	.00	.00	.00	.00	2.18	2.23	.35	.03	3.43	.00	T.	.00	8.22
1889–90	.00	.81	.27	2.21	.45	7.30	.85	.58	.00	.00	.00	.00	12.47
1890–91	.00	.00	.70	.00	2.15	.67	.00	2.33	.19	.36	.00	.00	6.40
1891–92	T.	.00	.33	.03	.00	.76	1.00	.47	1.61	.....	.26	.00	4.46
1892–93	.00	.00	.00	.00	.27	.56	2.73	.26	1.53	.13	.00	.00	5.48
1893–94	1.04	.00	.00	.29	.15	.88	.48	.54	.24	T.	.03	.00	3.65
1894–95	.00	.00	.....	.00	T.	3.68	2.66	.53	1.01	.00	.00	.00	7.88
1895–96	.00	.00	.00	.80	.14	.00	1.31	.00	1.45	.....	.00	.22	3.92
1896–97	.12	.00	.00	.70	.17	.82	1.86	1.17	.82	.00	.00	.00	5.66
1897–98	.00	.00	.00	.00	.00	.00	.60	T.	.00	.00	.00	.00	.60
1898–99	.00	.00	.00	.00	.00	.29	.37	.00	.48	.00	T.	.00	1.14
1899–1900	.00	.00	.00	.68	.88	.31	.31	.00	T.	.21	.42	.00	2.81
1900–1901	.00	.00	.01	.00	1.66	.00	.73	3.18	.00	.00	.28	.00	2.86
1901–2	.00	1.75	.00	.52	.07	.00	.17	.86	.14	T.	.00	.00	3.51
1902–3	.00	.00	.00	T.	.84	.21	.02	.50	.35	1.00	.00	.00	2.92
1903–4	.00	.00	T.	.00	.00	.00	.00	.76	1.20	.00	.00	.00	1.96
1904–5	.00	.30	.00	.00	.00	.60	.70	1.60	2.90	.00	T.	.00	6.10
1905–6	.00	.00	.00	.00	1.25	.00	1.00	1.00	2.00	1.50	T.	.00	6.75
1906–7	.00	.00	.00	.00	.65	2.25	[a]	[a]	[a]	[a]	[a]	[a]	[a]
Mean for 29 years	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.78

[a] Record not available.

The following table represents the average monthly precipitation during the time noted after the name of station. In the last column the normal annual precipitation, so far as records indicate, is shown.

Normal precipitation.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Barstow, Cal., 5 years[a]	0.56	0.34	1.15	0.19	0.00	0.00	0.10	0.00	0.12	0.85	0.58	0.23	4.12
Tehachapi, Cal., 31 years	1.39	2.49	1.63	1.30	.40	.10	.01	.11	.09	.45	.56	1.96	10.49
Mohave, Cal., 31 years	.90	.84	.71	.17	.03	.05	.08	.04	.07	.25	.40	1.26	4.80

[a] Data doubtful.

Other records covering a period of eight years show that the mean annual precipitation at Barstow for that period is 2.85 inches.

TEMPERATURES.

The great elevation of Antelope Valley—between 2,300 feet at its lowest part and over 4,000 feet along portions of its margin—modifies the heat of this part of the Mohave Desert somewhat, though temperatures of 110° or more are not uncommon during the summer. The nights are usually cool, and the "livableness" of the region is in consequence greater than it otherwise would be. During the winter months the thermometer sometimes drops as low as 25° near the foothills and considerably lower in the valley. It is stated that on December 30, 1895, one of the coldest days ever experienced in the valley, the temperature fell to 6° above zero near Lancaster. Ice forms not uncommonly, and occasionally snowstorms sweep across the whole extent of the valley. It is generally believed by the settlers that the winter temperature of the belt of low foothills along the southern margin of the valley is considerably higher than that of the lowlands to the north. Temperature records in proof of this are not available, but such a warm foothill belt exists elsewhere in the State where topographic conditions are somewhat similar. The record of temperature for Mohave, the elevation and general surroundings of which resemble those at the margin of Antelope Valley, are presented in the following table as indicating probable conditions in the valley:

Monthly and annual mean temperature at Mohave.

[Elevation, 2,751 feet.]

Years.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual mean.	Extremes.	
														Max.	Min.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1891....	44.1	45.0	52.3	60.5	72.3	74.4	87.5	89.4	74.7	67.6	57.4	46.0	64.3	112	18
1892....	45.9	48.8	54.2	58.0	69.0	76.9	84.8	88.1	79.5	63.7	54.7	43.7	63.9	115	25
1893....	50.7	48.2	50.4	54.7	70.4	76.6	87.6	85.4	69.2	60.3	52.4	48.3	62.8	106	28
1894....	41.0	42.5	53.7	64.0	69.8	69.8	84.0	89.0	76.0	67.9	58.3	44.7	63.4	108	16
1895....	42.9	50.2	51.0	59.9	68.7	80.3	84.3	85.5	73.9	66.1	50.3	42.8	63.0	111	18
1896....	48.5	50.1	53.4	52.3	60.8	83.5	88.3	83.7	74.1	65.6	52.0	47.3	63.3	111	25
1897....	43.8	43.8	45.5	62.1	75.9	80.0	86.6	87.5	72.3	60.7	54.2	42.3	62.9	113	15
1898....	37.8	51.4	48.3	62.1	63.9	80.0	87.8	88.0	78.2	64.4	53.3	42.4	63.1	115	16
1899....	45.9	48.3	53.5	61.3	60.9	78.9	85.7	75.3	79.4	60.7	53.4	45.4	62.4	108	18
1900....	49.1	50.0	54.8	51.0	66.8	78.6	83.2	77.1	64.2	60.3	54.5	47.8	61.1	107	25
1901....	43.2	46.6	52.6	59.2	65.5	76.4	85.2	81.0	70.7	63.7	55.4	45.7	62.1	108	20
1902....	45.5	49.7	48.7	54.4	60.0	77.1	80.4	76.8	77.3	62.2	53.8	42.0	60.7	105	20
1903....	46.5	42.0	49.0	51.4	68.7	76.2	83.8	86.6	74.2	67.1	56.8	50.4	62.7	106	15
1904....	46.4	53.0	55.0	61.0	80.2	82.2	83.3	90.8	79.0	66.6	57.2	56.6	67.6	107	23
1905....	48.6	48.4	52.8	60.2	61.8	77.4	95.8	90.8	79.3	77.0	56.4	46.0	66.2	114	20
1906....	46.9	52.2	54.6	56.5	65.2	77.4	91.2	86.8	76.6	67.0	49.6	47.4	64.3	108	20

WIND.

No records of the velocity or frequency of wind in the Antelope Valley region are available, but all who have lived there testify that during the spring months the region is swept by strong winds, which have occasionally injured growing crops. The writer's experience is limited to the months of November and December, 1908, December, 1909, and January, 1910. During a portion of this time the winds were not objectionable. Occasional storms from the west so filled the air with dust and finely comminuted alkali that it became unpleasant to work outdoors. When these winds are preceded by rain, they are merely disagreeable, but under other conditions and in some portions of the valley the finely blown particles act as might a keen knife upon alfalfa or other plants whose stems contain insufficient woody fiber to withstand the repeated attacks of the sand particles. The large areas of eolian sands on the eastern margin of the valley afford definite evidence of the activity of the winds. It may be remarked here that the settler who has his agricultural interests most at heart is careful to plant hardy windbreaks, usually cottonwood or black locust, along the west side of his buildings. In some places the natural desert growth has been used for protection, rows of sagebrush and mesquite being left at intervals when a field is cleared for planting. In this way the force of the wind on the tender shoots of grain or alfalfa is somewhat broken until a stronger growth is made. Such natural windbreaks, unfortunately, are said to become harboring places for jack rabbits and other pests.

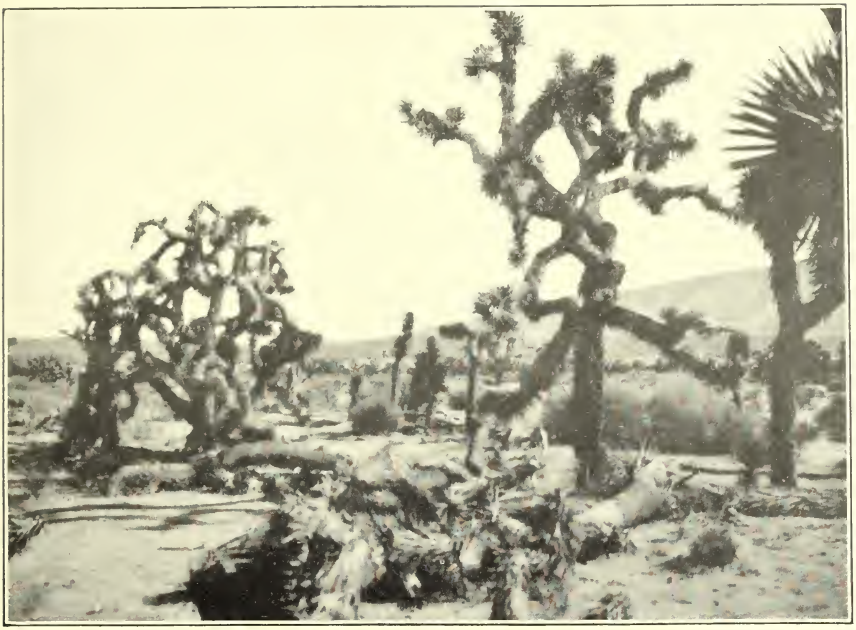
HEALTHFULNESS.

This region, with its large number of sunny days in winter and its exceptionally dry summer climate, is, like portions of Arizona, an ideal place for those suffering with pulmonary complaints. Despite the high summer temperatures sunstroke is practically unknown, and hard manual labor, even in the sunshine, is neither unpleasant nor enervating provided ordinary precautions as to diet and drink are observed. The general purity of the deeper ground waters must have not a little to do with the good health of those living in the region.

NATURAL RESOURCES.

Animal life in the region studied is, with some exceptions, not now abundant. Jack rabbits and coyotes are a nuisance to the ranchers, but periodical onslaughts upon them afford sufficient protection. Antelope have become extinct in the lowlands and deer have almost disappeared from the mountains, as they afforded sport which appealed most strongly to the wanton instincts of the early hunters.

Of desert plants valuable to man there are a number. In Antelope Valley the yucca grows both scatteringly and in thick groves of



A. YUCCAS ON MOHAVE RIVER SOUTH OF RANCHO VERDE.

See page 19.

B. MUD FLOW FROM CLOUD-BURST IN CANYON OF MIDWAY OIL DISTRICT.

See page 28.

fantastic appearance, and its peculiar cellular wood has been used in the manufacture of a fiber cloth. Some years ago the cutting and hauling of the wood to railroad points for shipment to the factories was remunerative, but cutting has been prohibited because the windbreak value of these trees to the valley was thus greatly impaired. The trunks of the trees are even yet occasionally used in fence and shed construction, and for fuel. In Plate II, *A*, a yucca thicket on Mohave River is shown. In some parts of the valley lands, where the ground waters are near enough to the surface to give a certain, even if very small, amount of moisture to the soil, the usual desert growth becomes more abundant and of great size. Such conditions have produced the mesquite trees along the wash of Rock Creek to the south and southwest of Lovejoy Buttes and in the area of flowing artesian wells of the valley. These trees and others of the more woody varieties of brush furnish a fair fuel to the settlers. The higher portions of the San Gabriel, San Bernardino, and Tehachapi ranges receive a greater precipitation than the valley lands and support a good stand of conifers and oak.

Practically all the developed part of Antelope and Mohave valleys is devoted to agriculture; the undeveloped portion makes range for stock. In the western end of the valley, which is comparatively free from brush and is at present nonirrigable, a considerable area is planted in grain. Along the southern margin of the valley, from Neenach to Rock Creek, and in Leonis and Anaverde valleys, the almond, fruits (among which are the apple and pear), and other produce typical of a temperate climate are grown. The almond industry of the lower foothills, along the south margin of Antelope Valley, had its inception in the discovery that wild almonds grow in the canyons of the near-by ranges.

Where artesian waters have been used for irrigation in Antelope Valley, alfalfa, fruit, and many vegetables are grown, but much of this region will remain uncultivated until effective methods shall have been devised to remove alkali from the upper soil and subsoil.

Of the mineral resources in the region only brief mention need be made. Gold has been mined in the San Bernardino, Tehachapi, and San Gabriel ranges, but the most productive districts at present are those in the Rosamond Buttes and east of Victorville.

Plaster mills at Palmdale use in part gypsum obtained from the foothills southwest of the town. Limestones and fancy marbles suitable for building and for cement manufacture exist in the buttes near Victorville, and the ornamental portions of several of the larger office buildings in San Francisco are built of these marbles. Limestones also exist in the Tehachapi Range and in the mountains on the southern margin of Antelope Valley.

The volcanic breccias and ash of the Fairmont Buttes are being utilized in the Los Angeles Aqueduct as an admixture for the cement used in construction along the conduit. The material is quarried and crushed at a mill about 1½ miles northeast of Fairmont. Sodium sulphate and sodium carbonate exist as efflorescent deposits in the low parts of the valley depressions. Near Buckhorn Springs some prospecting for these salts has been done, but no commercial development has been attempted. Clay suitable for pottery has been found near Rosamond, and brick clays exist at a number of places along the southern margin of Antelope Valley.

GEOLOGIC FEATURES.

PHYSIOGRAPHY.

Geologic and structural conditions are so intimately related to the whole problem of water supply in this valley that a brief sketch of the history and character of the formations must precede the discussion of the water resources.

Though no detailed geologic study has been made in any part of this region, many facts indicate that Antelope Valley is, except in its minor features, a faulted block along whose southern and northwestern margins strong uplifts have resulted in the production of the Tehachapi, San Gabriel, and San Bernardino ranges. The Rosamond Buttes to the north are also probably the result of uplifts. These buttes seem to be separated from the valley by faults, but the heights east of them and the similar irregular bedrock region of low relief east of Redman and north of Lovejoy Springs and Turner dry lake, appear to represent higher parts of the valley floor, separated from the lower parts beneath the valley proper only by gentle flexures.

The first effect of the crustal deformation that produced the valley and its bordering heights was to stimulate erosion, and in consequence the valley became the receptacle for the detritus removed from the mountains.

The southeast face of the Tehachapi Range is a great escarpment having a vertical rise of over 2,500 feet in a distance of less than 3 miles from the edge of the alluvium. Springs along the steep base of the mountain mass and deformations in the Quaternary gravels of the valley along axes parallel to the range point to the existence here of an extensive fault. Though on a somewhat less grand scale, this southeast face of the Tehachapi Range is comparable to and may be a continuation of the eastern front of the Sierra Nevada, which has long been known as a profound fault scarp.

Both the San Gabriel and San Bernardino ranges are even more readily recognizable as of structural origin than the Tehachapi. As

has been shown by Mendenhall,[1] these ranges are bounded by faults along which the region of high relief has been uplifted.

The course of the San Andreas fault, along which in various portions of California movement within historic times has taken place,[2] is clearly expressed on the accompanying map as a chainlike series of long, narrow, inclosed basins or troughs constituting the depression in which lie Elizabeth and Hughes lakes and Leonis and Anaverde valleys immediately south of Portal Ridge. A view of the fault zone looking northwest from Anaverde Valley is shown in Plate V, *B* (p. 42). From Palmdale southeastward along the foot of the range the feature is less distinct topographically, but its geologic effects have been no less profound. This fault crosses the San Gabriel Range several miles south of Cajon Pass and extends along the south side of the San Bernardino Range and through San Gorgonio Pass into the Colorado Desert.

Mr. Homer Hamlin[3] has pointed out that to an observer stationed on the Tehachapi Range near Cottonwood Creek a distinct linear arrangement of the buttes extending southeast from Willow Springs toward Rogers dry lake is visible, and that the general effect produced is that of a long, dissected fault scarp facing south. When examined more in detail the local conditions emphasize Mr. Hamlin's view. No bedrock is exposed west of the butte at Willow Springs, but the gentle southeast slope of the alluvial fans along the foothills of the Tehachapi is abruptly replaced at Willow Springs by a south-facing escarpment, ranging in height between 50 and 100 feet, and extending north 75° W., for a distance of about 5 miles. The escarpment is clearly of structural origin. Whether the deformation in the gravel deposits is due only to displacement in the hard rocks below, or to a line of actual fracture of the gravel beds themselves, it has resulted in a difference of about 100 feet between the elevation of the part of the plain to the north and of Antelope Valley to the south, the latter being the lower. More important yet in the economy of the region is the influence of the escarpment in determining the location of springs. Thus, Bean Springs, the several outflows at Willow Springs, the spring at Gerblick's mine, the springs on the south foot of the butte northwest of Rosamond, Indian Springs, and Buckhorn Springs, all coincide closely with a line projected from this escarpment southeastward along the steep south face of Rosamond Buttes. Although the elevation of the buttes east of Indian Springs is low, this escarpment is none the less pronounced as far as the west margin of Rogers dry lake. Beyond this it appears to merge with the bedrock height of land along

[1] Mendenhall, W C., Water-Supply Paper U. S. Geol. Survey No. 219, 1908, pp. 14–18.

[2] Report of State Earthquake Investigation Commission on the California Earthquake of April 18, 1906, vols. 1, 2, and atlas, Carnegie Institution of Washington, Washington, D. C., 1908.

[3] Oral communication.

the San Bernardino-Los Angeles County line, but it was not farther examined. The northwestward projection of the escarpment passes with a slight northward swing into the Tehachapi at the low portion of the range in T. 10 N., R. 16 W., and thence falls approximately in line with a fault determined by Lawson[1] during his studies of the Tehachapi Valley system. It is noticeable that in both systems the uplift is on the north side of the fault. The direct bearing of this structural feature on the water supply of Antelope Valley gives it an importance second only to that of the faults resulting in the Tehachapi and Sierra Madre uplifts.

The physiographic history of the buttes and heights of land east of the Antelope Valley is obscure. No such striking evidence of the origin of the region as that just presented for the Rosamond Buttes was found, yet erosion seems inadequate to fully explain the topography. It is tentatively suggested that this region of irregular buttes and shallow intervening valleys has been less deformed by

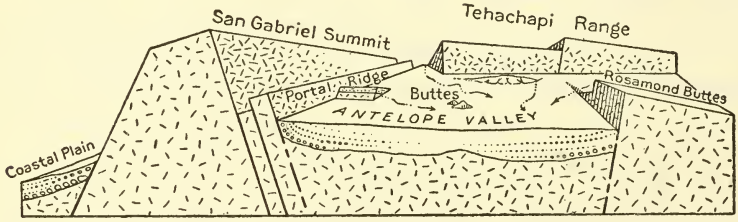


FIGURE 1.—Diagram showing probable block and fault systems of the Antelope Valley region.

depression or elevation than either Antelope Valley or the marginal ranges.

Figure 1 is a purely theoretic representation of what are believed to be the main blocks and faults involved in the production of the larger physiographic features of the Antelope Valley region. The small northwestward-dipping block in front of the Portal Ridge block, represents the Antelope Buttes near Fairmont. As the tuffs on the west side of these buttes dip at angles of 35° to 55° northwestward—a direction at right angles to the San Gabriel fault system—it is assumed that the underlying granite has been tilted in accordance with the Tehachapi rather than the San Gabriel faults.

NON WATER-BEARING ROCKS.

METAMORPHIC AND GRANITIC MARGINAL ROCKS.

In discussing the sources of the water supply and the conditions under which it exists, the rocks of the Antelope Valley region may be divided into two classes—water-bearing and nonwater-bearing. For

[1] Lawson, A. C., The geomorphogeny of the Tehachapi valley system: Bull. Dept. Geology Univ. California, vol. 4, 1906, pp. 431–462.

all practical purposes the rocks of the margin of the valley, which include a number of formations, are nonwater-bearing. This is true not only of the granitic and metamorphic rocks of the Tehachapi and Sierra Madre ranges and of the volcanic and granitic buttes, which limit the valley on the north and east, but of the older nonmetamorphic sediments in parts of the region. In the strictest sense, of course, some of these marginal rocks do contain water, but except where springs or water-filled fissures exist the supply they yield is usually inadequate for economic use. As previously indicated, the alluvium of Antelope Valley rests on the extension of the marginal rocks. Evidence of this is found in the buttes which at Fairmont and between Willow Springs and Del Sur project above the valley floor.

As the metamorphic and granitic marginal rocks make an inclosed basin more or less completely filled with gravel, their impervious character prevents the loss downward of practically any of the waters which may be contained in the gravels. In the time allotted to the field work for this report only a generalized map of the line of contact between the bedrock and the alluvial filling of the valley could be made, but a few notes were obtained on the character of the older rocks.

The oldest rocks of the region are probably the metamorphic rocks of the Tehachapi and Sierra Madre ranges. In the Tehachapi these rocks are principally limestones which stand in bold, steep bluffs about the heads of the several short streams flowing from that range into Antelope Valley. Granitic rocks which appear to be intrusive in the limestones have been noted on Livsey Canyon and below Knecht's ranch on Cottonwood Creek. Here schists and slaty rocks, apparently metamorphic sediments, are associated with the limestones. The age of these rocks is not known, but they resemble in appearance and relations the great metamorphic series of the granitic complex along the crest of the Sierra Nevada. On the southern slope of the southwest end of the Tehachapi the limestones are well exposed and they appear to extend toward Gorman station, but they were not traced farther south than the boundary line between Kern and Los Angeles counties. Granitic rocks occur in the Sierra Pelona, but no attempt has been made to map them. South of Fairmont, in Portal Ridge, a light-colored biotitic granite which has been greatly sheared and crushed in consequence of severe faulting parallel to the San Andreas rift valley is well exposed on the walls of Elizabeth Lake tunnel and at many points in the surrounding hills. Thence southeastward almost to Palmdale the bedrock series of Portal Ridge consist largely of metamorphic rock with some granite. Particularly good exposures of various coarse metamorphic schists, both hornblende and micaceous, are found along the narrow ridge just northwest of Amargosa Creek in sec. 30, T. 6 N., R. 12 W. Quartz Hill, at the extreme northwest

corner of the same township, is a granitic outlier which has resisted erosion sufficiently to become a prominent topographic feature. This butte near its west end exposes a basic rock, perhaps diorite, which should be a good road metal. Southwest of Anaverde Valley the main portion of the San Gabriel Range appears from a distance to be largely granitic. Broad zones of reddish rocks that contrast strongly with the gray masses of the granite are said to be intrusive volcanic dikes.

The geologic conditions in the San Gabriel Range from Tilghman southeastward are unknown to the writer, but the wash material along the margin of this part of the valley and the general appearance of the range indicate that it, too, is largely granitic and metamorphic.

The buttes along the east side of the valley are, so far as visited, granitic and metamorphic, and in some of them the slates and schists of the latter series seem to predominate; others are almost entirely composed of a rather dark-colored and sometimes reddish biotite granite. Although the filling between these groups of buttes is alluvial, it is probably quite thin, and all buttes and heights of land which characterize this part of the region are thought to be but the topographic expression of a single underlying granitic mass, the surface of which lies only a moderate depth below the valley level. West of a line drawn approximately from the middle of T. 6 N., R. 10 W., northeastward to and along the eastern margin of Rogers dry lake, the gravel filling of Antelope Valley probably thickens. On the geologic map this line is indicated in a general way by the western margin of the area of nonwater-bearing rocks, of which Lovejoy and Black buttes are a part, and though the butte region is not considered particularly favorable as a source of water supply, it is not impossible that potable water may be found in some of the larger depressions mapped as a part of the nonwater-bearing area.

A somewhat similar condition as to possible water supply is found in the irregular region of buttes and depressions whose southern margin extends from Willow Springs eastward almost to Rogers dry lake. Only a few of the outcroppings of this rock mass were examined, but it seems probable that the granitic and metamorphic rocks, which certainly occur in a portion of the region, are at other points marked by flows or extrusions of volcanic rock. The small group of low buttes in the northwest portion of T. 8 N., R. 13 W., and that about a half mile west belong to the granitic and metamorphic series, and their presence so far from the margin of the valley indicates a comparative shallowness of the basin at this point.

UNALTERED SEDIMENTARY ROCKS.

In certain portions of the region sedimentary rocks of unknown age have been found, but their relations to the bedrock series and their lack of alteration suggest that they probably belong to the Cretaceous or a later period of deposition. The largest area of such rocks so far observed comprises a series of much folded yellowish-brown sandstones at the extreme west end of the valley. Violent stresses, due to their proximity to the opposing faults of the Tehachapi and San Bernardino ranges, have greatly folded the beds here exposed. North of Quail the general trend of this series is toward the southeast, and immediately west of Quail structural folds are traceable for a short distance. This series of sandstones is overlain, apparently uncomformably, by a later, less coherent series of sands and gravels which are a part of the water-bearing rocks of the region, and at the line of unconformity north of the Gorman station road springy conditions prevail. Exposures of the older series, indicative of considerable deformation, were noted along the south side of the road between Quail post office and Barnes ranch. No evidence of the age of this series of sandstones and shales has been found, but the degree of consolidation and general physical appearance suggest the lower Miocene or older, as it occurs in portions of the Sunset-McKittrick oil regions.

VOLCANIC ROCKS.

Immediately south of the area exhibiting this narrow strip of sediments is a region composed of reddish or purplish brown volcanic rocks, which extend up the first ridges to an elevation of about 4,000 feet. The relation of this volcanic mass to the sediments on its northern side is unknown, but it appears to be in part at least faulted against them. The volcanic rocks are well exposed on Gookin Gulch from its mouth southward for about a mile, where the fracturing and crushing of the rocks along the San Andreas fault zone obscures their character.

Although some of this lava is rather cellular and shows evidence of having been poured out at or near the surface, tuffaceous phases of it do not predominate except in the Antelope Buttes near Fairmont. The structural and geologic features of this particular group of hills are interesting and may be best explained by reference to figure 2.

The more westerly butte, *a*, consists of beds of heavy, roughly stratified tuff of basaltic material, with some granitic bowlders, the whole series having been tilted until it dips from 35° to 55° toward

the northwest. These beds, coarse at the top, grade downward into more regularly bedded gray and dirty white tuffaceous sandstones, which at some horizons contain indurated conglomerate layers and creamy-white tuff beds. The underlying granites on which these tuffs were deposited make up most of the easterly butte *b*, and just north of the springs, in sec. 30, T. 8 N., R. 14 W., on the west side of the creek, the relation between the granite and tuff is clearly shown. It is believed that much of the water which seeps out here is derived from the porous beds of the tuff series concentrated at the impervious granite contact.

The flow of lava shown at *a* is at the northern end of the west butte, where it is intercalated with the heavier tuffs. A clue to its character is found in the presence of granite bowlders, formerly part of the near-by tuff, which have been almost completely surrounded by the lava flow.

The source of these tuffs and the flow is unknown, but judging from the coarseness of the former, it is believed to have been not far distant.

Although granitic rocks were noted at the east end of the Rosamond Buttes, near Indian Springs, and at points along the scarp which

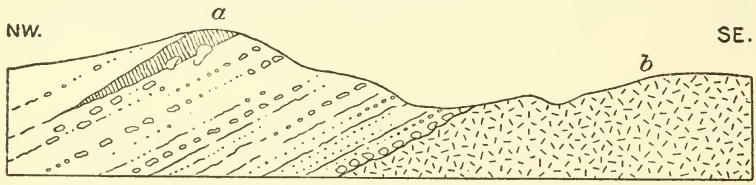


FIGURE 2.—Section of Antelope Buttes, showing attitude of tuffs and lava at *a*, and their relations to granitic rocks at *b*.

extends toward Rogers dry lake, the bulk of the buttes between Rosamond and Willow Springs is a pinkish to dirty yellow rhyolitic lava. The data at hand are insufficient to determine the source or extent of these rocks.

Outcroppings of the rock are as a rule craggy and irregular, but where the material has been loosened by decomposition more regular slopes, made up of platy fragments, are common. The usual color of the volcanic buttes is a fine pink, but in places where the rock is decomposed or tuffaceous it grades into a yellowish or dirty gray. Where the texture is firm and jointing is not too pronounced, the rock makes a fair building stone; the new hotel at Rosamond and the cottages and other buildings at Willow Springs are built of rhyolite from the butte just northeast of the springs.

The dikes intruding the granites southeast of Palmdale (p. 24) may be a part of the granitic complex.

WATER-BEARING ROCKS.

ORIGIN AND DISTRIBUTION.

The rocks of the region which contain sufficient water for economic use have been classed, irrespective of their age or character, as water-bearing. These rocks are composed almost wholly of the unconsolidated gravels, "cements," sands, and intervening clays, all of which have been derived from the mountain ranges of the region by erosion and redistributed in the lowlands.

So far as observed, all the water-bearing rocks of the Antelope Valley region belong to the class of transported deposits. From the rather limited present knowledge of the history of the ranges of the surrounding region it appears that the erosional effectiveness of most of the smaller streams entering the valley dates from the uplift of the Tehachapi and Sierra Madre ranges. It is presumed that before this uplift these mountains, though they may have existed as a region of relief, were of rather moderate elevation, so that the streams draining them were not active. These streams were probably stimulated into great activity by the uplift or series of uplifts that caused the topographic differences between Antelope Valley and the Tehachapi and San Gabriel ranges. The uplifts were probably distributed over a comparatively short geologic period. As the mountains became higher, the rainfall and the grades of the streams and their erosive power increased, so that steep, narrow gulches and canyons were cut into the sharp escarpments bounding the ranges. The volume of material thus ground up and removed from the mountain masses was enormous, for with torrential rainfall and steep grades streams have great transporting power. In the region at the south end of the San Joaquin Valley, about 75 miles west of Antelope Valley, blocks of heavy sandstone 10 or 12 feet in diameter have been carried from their outcrops in the mountain several miles out on the flat beyond the mouths of the canyons. Such happenings as this are unusual, but the general result of the sudden expulsion of detrital material borne along in a torrential stream from a constricted canyon on to an open plain is to produce a fanlike deposit, the apex of which is just at the mouth of the canyon. These alluvial fans, detrital cones, or deltas, as they are called where formed by larger rivers, are well-recognized features throughout the arid West.

An ideal diagram and sections (fig. 3) of an alluvial fan have been prepared to show the arrangement of the débris about the mouth of canyons in drainage basins whose precipitation is torrential in character. This sketch is based on a study of a number of typical fans in the San Joaquin Valley, but it is applicable to this region as well. An examination of the plan, which illustrates one phase of fan development, shows that the stream leaves the mouth of its canyon with

full force, but at the margin of the plain toward which it is flowing it spreads, so that it drops most of the heaviest material. The stream itself, which in the canyon has been confined to a single channel, diverges into several distributaries, each of which carries its own load of heavier gravels and sands, to be deposited in the order of their weight as the transporting power of the water diminishes. If one of these distributaries be followed downward along its course, it will be noted that low levees of gravel in the upper courses and of sands and mud farther down have accumulated on each side of the shallow channels. This linear arrangement of the material has been indicated on the diagram. It is characteristic of the fan type and undoubtedly plays a considerable part in allowing free percolation

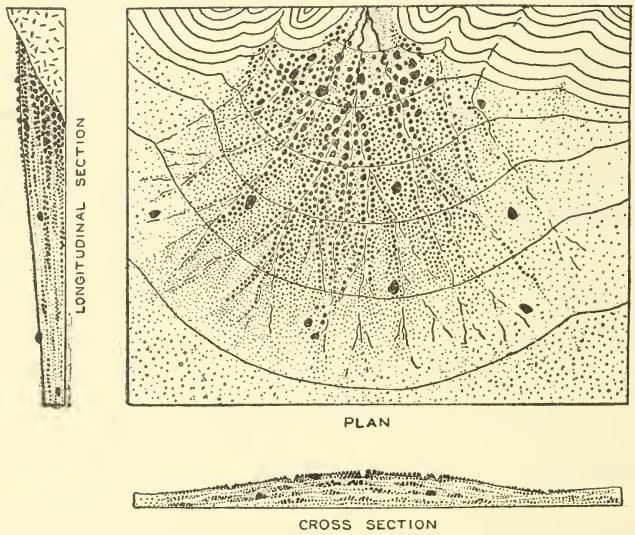


FIGURE 3.—Diagrammatic plan and sections of alluvial fan, showing arrangement of débris. Sketch contours do not show channeling of fan.

of water through the material. The drawing also indicates the continued division of the distributaries and their gradual extinction around the lower margin of the fan, where the finer material comes to rest. So far as observed, the end point of this process of deposition is to be found in the thin, irregular flows of mud left on the lower slopes. Such deposits are in some places thick enough to obliterate the low bunchy grasses across which they have spread. A typical deposit of this character is illustrated in Plate II, *B*, which is a view taken several weeks after a cloud-burst in one of the canyons in the Santa Fe-Midway oil district, in the southwestern part of the San Joaquin Valley. The channel along which this material flowed shows in the picture as a faintly marked depression in front of the horse and rider, and the margin of the mud levee on each side of the

channel extends from the point where the horse is standing toward the lower left-hand corner of the picture.

To gain a complete understanding of the growth of the fan it must be remembered that the description just given covers but a single phase, which may be repeated many times before the fan reaches its maximum development. Thus, after a period during which a certain arrangement of bowlders and gravel and sand may have been made and more or less well-defined channels formed, new distributaries may be established and other deposits, perhaps of different texture and material, may be laid down so extensively as to conceal those of an earlier period. In this way such an arrangement as that indicated in the longitudinal and cross sections may result. The main facts to be emphasized in regard to this mode of accumulation are that the detrital material of the fan exhibits a generally irregular arrangement, but grows finer as its distance from the source of material increases.

The alluvial fans about the margin of Antelope Valley are of this character, and in their growth and extension into the lowlands they have merged to produce the gently undulating floor of the valley. They attain their best development along the foot of the higher ranges. Perhaps the most typical, though not the largest fans, lie at the mouths of the small canyons south of Del Sur.

PHYSICAL CHARACTER.

As the valley floor to an unknown depth is made up of detrital material which has been deposited in the manner just described, it is evident that there will be an intermingling of material from different points in various parts of the valley. But it is also true that the rocks predominating around the source of the detritus are likely to predominate in adjacent valley deposits. In such a comparatively small basin as the Antelope Valley, however, the differences between the soils, except those of texture, are not particularly marked. Thus in a broad and indefinite zone from Palmdale northwestward through Fairmont to the extremity of the valley and thence northeastward along the margin of the Tehachapi Range the superficial deposits contain a considerable amount of granitic and schistose material, with some limestone. The soils south of the Rosamond Buttes and north of Fairmont contain decomposed and transported volcanic material intermingled with the granitic grains. In the vicinity of the dry lakes the texture of the soils is fine, like that of the clays which underlie much of this region.

The well records for the valley region indicate that the deeper deposits do not differ greatly from the gravels, sands, and clays of the surface. (See pp. 37–44.)

STRUCTURE.

Broadly considered, the great alluvial filling of the structural depression of the Antelope Valley is composed of lenticular and irregular beds which dip at low angles away from the bounding ranges and buttes. These gravels, sands, and clays show no evidence of deformation except at some points along the valley margin.

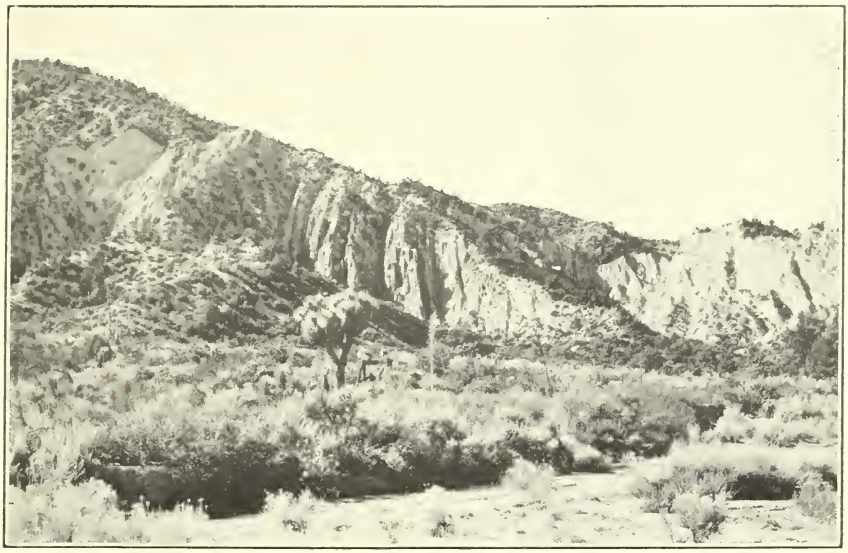
At and just north of the central portion of T. 9 N., R. 15 W., a well-defined ridge, parallel to the Tehachapi, breaks the even slope of the great fan of Cottonwood Creek. So far as examined the gravels and clays exposed in this ridge, although they have been folded and faulted, are not unlike those near by, which lie as originally deposited.

These hills, which express an anticlinal fold, either in the fan itself or in material only slightly older, prove recent structural changes in the region. Deformation of a similar character is evident in gravels at the west end of Antelope Valley. Along Liebre Creek these beds show dips ranging from 12° to 40°. Immediately northwest of the junction of the Bakersfield and Liebre ranch roads a dip of 70° to the north in granitic gravel was recorded. Southwest of Palmdale the San Andreas fault zone issues from behind Portal Ridge and for a short distance involves the gravels forming the margin of the valley deposits. They have, in consequence, been sharply folded and at some points even overturned by the violence of the dislocation. Good exposures of these tilted gravels and sands are to be found along the road from Palmdale to Anaverde ranch, especially in sec. 29, T. 6 N., R. 12 W. From Tilghman southeastward along the San Gabriel Range a definite inface marks the southern margin of the valley filling. Dips of 10°, sufficient to indicate deformation, have been noted on this inface. Plate III illustrates two phases of deformation in these marginal beds: *A* shows clearly a complete overturn of the gravels when faulted against a bedrock surface; *B* shows a gravel inface in which the beds are less disturbed.

No deformation was observed along the east side of Antelope Valley, but enough evidence has already been given to indicate that the valley filling is an alluvial deposit, undisturbed except along the margins, which have been flexed by the dislocations accompanying the uplift of the mountains.

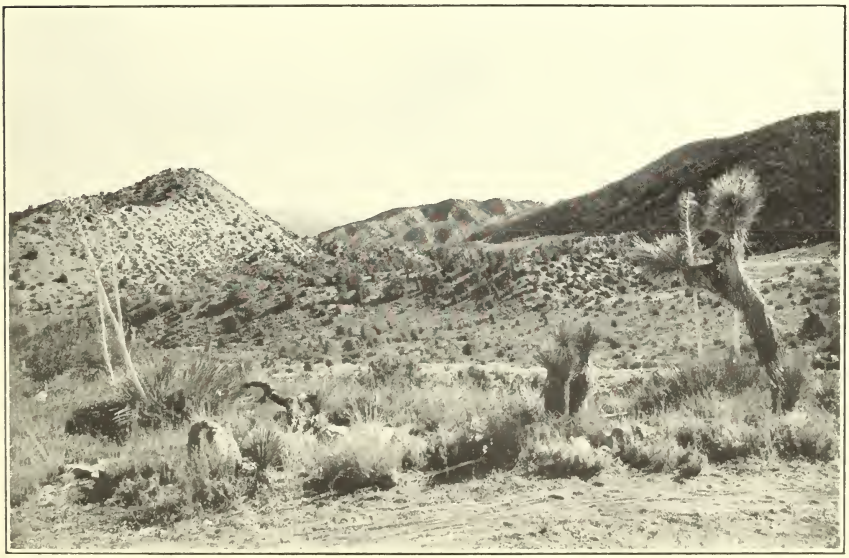
SAND DUNES.

Antelope Valley is a region of high winds, which during part of the year sweep across the broad, unprotected plain with considerable violence. The usual direction of these winds is from the west, and in consequence along the eastern side of the valley chiefly, but in other places as well, considerable sand-dune material has accumulated. Through the gradual growth of brush and grasses some of these



A. FAULTED, FOLDED, AND OVERTURNED ALLUVIAL BEDS NEAR HEAD OF CAJON CANYON.

See page 30.



B. GRAVEL INFACE ABOUT 6 MILES EAST OF TILGHMAN.

See page 30.

dunes have become permanent, but elsewhere they encroach upon the fields and drift across roads and fences whenever the winds attain any particular strength.

PLAYA DEPOSITS.

In the lower portions of the valley are broad, almost horizontal stretches of very finely comminuted clays and silts, irregular in shape and thickness but coinciding with the dry lakes in the lowest parts of the basin. As they contain a large amount of alkali, they are of little or no agricultural value.

The alkaline content of the soils in the lower portions of the region is almost wholly derived from the evaporation of such waters as reach these basins, either upon the surface or through slow upward movement of ground water. It is because of this action that saline incrustations occur where the ground-water level approaches the surface, as in the lower part of Antelope Valley and, on a smaller scale, in some of the small basins along the San Andreas fault zone, as well as south of Lovejoy Springs and east of Moody Spring.

WATER RESOURCES.

INFLUENCE OF RAINFALL.

The water resources of the Antelope Valley region, both surface and underground, depend solely on rain and snowfall within the drainage basin, of which, so far as now known, the Rosamond, Buckhorn, and Rogers dry lakes occupy the lowest part. This basin has an area of about 1,550 square miles, of which 930 square miles may be considered as valley land. Its southern and western margin is the divide between streams draining toward the sea and those toward the Mohave Desert. On the north and east side of the valley, where detailed mapping has not been attempted, the drainage conditions are less well determined and the outer limit of intermittent streams draining into the valley is unknown.

The records of Barstow and Mohave indicate that the mean annual rainfall in the region of low relief in the parts of the Mohave Desert north and east of Antelope Valley is less than 5 inches. The amount of surface water which reaches the valley from this region is therefore negligible. By far the greater part of its supply falls as rain and snow on the Tehachapi and San Gabriel ranges, which reach elevations of from 4,500 to 7,000 feet in the former to over 10,000 feet in the eastern portion of the latter. Records for this high region are not available except at Tehachapi, which has a mean annual precipitation of 10.49 inches during 31 years. In Little Bear Valley, in the San Bernardino Range, where conditions are comparable to those in

the San Gabriel Range, a 5-year record shows a mean annual precipitation of 27.60 inches.

The drainage basin of Antelope Valley, as far as known, has been roughly indicated on Plate I, page 8, with a heavy black line. The dotted black line within the area so outlined marks approximately the margin of that part of the basin capable of receiving and retaining waters derived from the whole drainage area. The heavy numbers indicate approximate rainfall where placed. The valley receives water most plentifully from the high region south of Little Rock and Tilghman, and in moderate amounts from the Tehachapi slopes, from the small area southwest of Palmdale, and from the partly wooded slopes of the Sierra Pelona south of Neenach.

It is not possible to present even approximate estimates of the amount of water absorbed by the unconsolidated filling of the main valley, but in view of the porosity of its marginal gravel fans and the upturned attitude of some of the superficial deposits along the foot of the mountains, it must be a large proportion of the surface water that reaches it. The slopes of the Tehachapi and San Gabriel ranges are not particularly absorptive, so that a relatively large part of the rain and snowfall must escape by evaporation into the air and as run-off into the near-by canyons and thence into the fan deposits (see pp. 27–29), the sands and gravels of which readily absorb the water that reaches them.

SURFACE SUPPLY.

Of the streams that debouch into Antelope Valley the more important have been briefly described on pages 12–13. Only two of these, Rock and Little Rock creeks, have been utilized for irrigation. Definite information regarding the history of these developments is difficult to get, but the following brief notes were obtained in the field:

DEVELOPMENTS ON ROCK CREEK.

In 1892 a periodical published in Chicago promoted a scheme by which the waters of Rock Creek were to be diverted at a point near the mouth of its canyon and distributed to lower lands both east and west of the stream. Open unlined ditches and flumes were constructed and lands were deeded in the expectation of irrigating about 1,000 acres. It is stated that settlers to the number of forty or more families built homes in the area that it was proposed to develop.

After two or three years the water supply was found to be inadequate and holdings were abandoned, except along the upper portions of the main canals where a supply could be relied upon. At present but four or five families reside continuously in the region.

The only records of flow available for Rock Creek are those tabulated below, which have been published at various times by the United States Geological Survey.[1]

Discharge of Rock and Pallett Creeks, Los Angeles County, Cal.

[Drainage area, 52 square miles.]

Date.	Locality.	Authority.	Discharge in cubic feet per second.
Jan. 4, 1897	Above Albergers Dam	J. B. Lippincott	5.3
Do	Tunnel approach	do	1.33
Jan. 4, 1898	Opposite dam site near where Pallett Creek enters Rock Creek.	do	5.27
Do	In development tunnel	do	1.33
Oct. 14, 1908	Above all diversions (1½ miles above Shoemakers)	W. B. Clapp	6.5
Do	Pallett Creek at road crossing near schoolhouse	do	1.8
Do	Below mouth of Pallett Creek	do	9.4

DEVELOPMENTS ON LITTLE ROCK CREEK.

The drainage basin of Little Rock Creek comprises about 78 square miles and undoubtedly gives a greater run-off during winter months than Rock Creek, with an area of 52 square miles, although the summer flow of the creek is considerably less, for a larger proportion of the drainage basin lies below the part of the range in which the melting of the winter snows is sufficiently retarded to affect the summer run-off. About 15 years ago C. F. Cole and others planned to develop these waters and organized the South Antelope Valley Irrigation Co. Diversion works were constructed on this stream about 6 miles above the mouth of the canyon and the water was conducted in an open canal nearly 7 miles toward the northwest to a reservoir about 2½ miles south of Palmdale and just west of the Southern Pacific tracks, as shown in Plate V, *A* (p. 42). This reservoir is a natural feature due to the uplift of low hills along the north side of the San Andreas fault zone in such a way as to block the channels formerly draining into Antelope Valley. Except for the building of a levee to prevent overflow of the railroad right of way, practically no construction was necessary to convert this depression into a reservoir of a capacity stated to be 5,500 acre-feet. It was originally planned to divert winter storm waters into this reservoir where they were to be held until the succeeding summer. The great length of the unlined canal, about 7 miles, and the porous nature of the ground which it traversed for much of this distance decreased its value greatly as a conduit. On March 2, 1898, the flow near the intake of the canal was 2.02 second-feet as measured by Bert Cole, engineer for the company owning the land.[2] After flowing a mile through the canal the water was reduced in quantity

[1] Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, p. 535. Water Supply Paper U. S. Geol. Survey No. 28, p. 190.

[2] From records of the United States Geological Survey.

to 1.60 second-feet, a loss between the two points of about 20 per cent. It is stated that at no time since its completion has the Palmdale reservoir been filled to its capacity, about 11 feet having been the greatest depth of water which it has held.

Although clay exists in the bottom of the reservoir, there must be loss by seepage at least along its northern side. The material exposed here is a roughly stratified gravelly and sandy deposit similar to the valley filling, except that it has been tilted and fractured along the San Andreas fault zone. One of the most recent indications of this faulting is a crack coinciding exactly with the north edge of the reservoir. In Plate V, *A*, the apparent terrace extending from the center of the picture downward toward the lower right-hand corner is the scarp along this fracture.

After the completion of the irrigation works and the expenditure (stated) of $182,000, water was distributed to users along the margin of the Antelope Valley between Little Rock post office and Palmdale. The population of this region at that time is not now known, but judging from the evidences of cultivation not yet obliterated it may easily have been 200. For about six years the colony prospered, but dry winters caused a great decrease in the flow of Little Rock, and it became impossible to get water to the reservoir. This led to the abandonment of most of the orchards at the west end of the colony.

Three years ago a cloud-burst carried away the headgates of the canal and since then both the Palmdale reservoir and its inlet canal have been dry except for such water as has accumulated in the former during the winter as run-off from the adjacent slopes.[1]

The only remaining phase of development of the waters of Little Rock Creek is that adjacent to Little Rock post office. This colony was organized in 1890 to make use of waters taken from the creek in sec. 22, T. 5 N., R. 11 W., at a point where the flow of the stream is brought to the surface under interesting conditions. For nearly 5 miles above this point the stream bed is dry during a large part of the year, but just below the point of diversion, in section 22, the San Andreas fault crosses the stream. As at many other places along this zone the north side of the fault seems to act as a submerged dam and the underflow of the creek has been forced to the surface. A flume was submerged in the gravels of the creek bed at this point, through which much of the underflow was led into a canal on the east side of the creek. From this canal the water was distributed over lands lying mostly within secs. 12, 13, and 14, of T. 5 N., R. 11 W. After suit with the South Antelope Irrigation Co. the users of this water compromised by allowing the company to use all water above 600 miner's inches, which was about one-half of the original amount filed upon by the settlers near Little Rock. The winter and spring of 1900 was

[1] For a full description of the project, with plate and maps, see Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, pp. 711–775.

a period of low rainfall in the drainage basin of Little Rock Creek, and to insure the certainty of their water supply during the following summer a steam pumping plant with a capacity of 80 to 100 miner's inches was installed over a shallow well in the bed of the stream a short distance above the natural dam at the fault line. During the irrigating season all the water used was lifted by this pump, but fortunately it has been found unnecessary to operate it since, as the supply furnished by the flume has been sufficient.

In December, 1908, the colony was in a more prosperous condition than any of those depending on surface waters for irrigating in the Antelope Valley. About 250 acres of pears, 200 acres of apples, and 50 acres of almonds are under cultivation, and fruit of high grade is produced, although it is believed by some of the growers that more water should be made available without an increase in acreage, to get the best results.

Substantial homes and well-kept orchards and gardens are evidence of what can be done in the region by thoughtful cooperation in developing and maintaining a water supply.

The following tabulations of discharge for Little Rock Creek are arranged from the records of the United States Geological Survey,[1] to which have been added a more recent measurement furnished by W. B. Clapp, of the United States Geological Survey, district engineer at Pasadena, Cal.

Discharge of Little Rock Creek, Los Angeles County, Cal.

[Drainage basin, 78 square miles.]

Date.	Locality.	Authority.	Discharge in cubic feet per second.
1896.			
April 20	In creek above headworks	J. A. Vogelson	7.16
June 2	do	J. B. Lippincott	1.04
July 7	(?)	Burt Cole	.26
1898.			
February 20	In flume	do	5.11
March 2	Above head gate	do	2.02
May	Estimated flow	do	a 5.20
June 4 to December 31			Dry.
1899.			
January	Estimated flow	Burt Cole	4.9
February	do	do	4.41
March	do	do	7.66
April	do	do	4.50
May	do	do	1.50
June	do	do	2.00
July	do	do	.2
August	do	do	.2
September	do	do	.2
October	do	do	.00
November	do	do	.00
December	do	do	1.00
1908.			
October 13	Head of flume near Little Rock post office.	W. B. Clapp	1.11

a Mean.

[1] Eighteenth Ann. Rept., pt. 4, pp. 402–405; Nineteenth Ann. Rept., pt. 4, pp. 526–528; Twentieth Ann. Rept., pt. 4, pp. 64, 540; Twenty-first Ann. Rept., pt. 4, p. 471; Water-Supply Paper 16, p. 193; Water-Supply Paper 28, p. 191.

UNDERGROUND WATER.

ORIGIN.

Antelope Valley lies between 60 and 75 miles from the ocean and its lowest portion is at least 2,300 feet above sea level. Springs at various points along the margin of the valley floor furnish a small amount of water to the gravels, but practically the full supply is derived directly from rainfall and run-off within its drainage basin. Of this whole area about 620 square miles is mountainous and about 930 square miles is valley land.

It has already been shown (pp. 27–29) that the unconsolidated filling of the valley is in excellent condition to receive and absorb the run-off from the mountains and that the gravels, sands, and clays which compose it are irregularly distributed and interleaved. The distribution of these lenses of detritus can not be determined by surface indications, but since practically all the wells of the valley find water

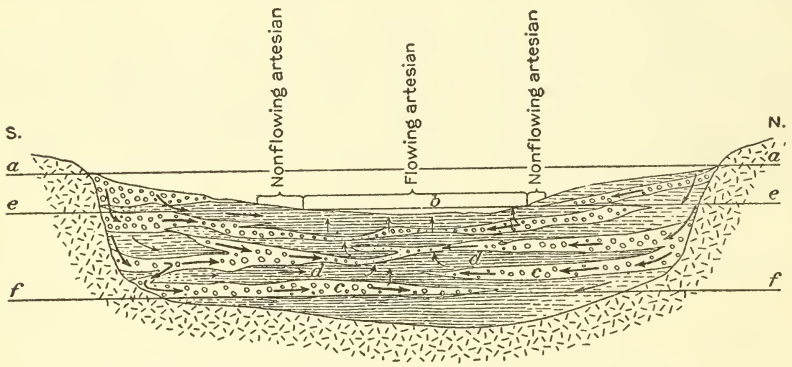


FIGURE 4.—Diagram showing artesian conditions in Antelope Valley.

if driven sufficiently deep, there must be a fairly free communication between the various beds of gravels and porous sands.

Figure 4 presents a hypothetical cross section of coalescent alluvial fans. The arrows show the direction of flow of waters entering the deposits at *a*—*a*, and their weight indicates the ease of transit of waters percolating through the gravels and sands. It will be noted that beneath the lowest part of the valley *b*, where it is assumed the finer clays and most compact sands are to be found, the waters circulate freely only in the coarser beds of sand and gravel as at *c*. Less porous beds, as the sands *d*, may permit the percolation of a certain amount of water near the fan margin, but toward the center of the valley the deposit becomes less porous and the contained water is held back in the coarser portion of the lens. If the material of the fan be thus saturated beneath *a*, a hydrostatic column may be produced, the height of which may be considered as the distance from *a* to *f*. The pressure that results is communicated to the waters confined

in the gravel beneath the less porous clays of the lower parts of the valley so that when released by a well or structural break they tend to rise toward the level *a*. As frictional obstruction to the free flow of water underground is inevitable, the water of no artesian well will rise to the level of its head, therefore, the yield of wells, other conditions being equal, indicates roughly the porosity of the strata in which they encounter water. The irregularity of the water-bearing lenses in Antelope Valley is thus attested, as there is considerable variation in the flow of wells believed to be otherwise similar. The best proof of the irregularity of the valley deposits is found in a study of the well logs furnished by drillers in the region. Fully 60 per cent of these records were made by one driller and they are believed to be reliable.

DATA CONCERNING WELLS.

West of Fairmont.—Of the half dozen or more wells examined in the portion of Antelope Valley west of Fairmont the logs of but two are available. These logs indicate that gravelly and sandy beds, with only a minor amount of clay, predominate to a depth of about 150 feet, below which the clay increases in amount. At the schoolhouse near Neenach water exists at a depth of 200 feet in a gravelly layer in this clay.

Vicinity of Willow Springs.—Information as to the character of the unconsolidated material in the valley near Willow Springs is meager. From the surface to a depth ranging from 75 to 200 feet, sand with a minor amount of clayey layers predominates. This sand rests on a compact clay bed which, in sec. 24, T. 9 S., R. 14 W., is about 150 feet thick. Surface water usually occurs at the top of this clay bed, but beneath it gravel lenses about 50 feet thick carry water which is stated to be under pressure, though with insufficient head to bring it above the surface. In the same vicinity water occurs beneath a second clay bed at a depth of about 320 feet, where rather coarse gravel and sand allow a free flow of fair water, also stated to be artesian and to have risen 251 feet in the well when struck.

At the Gerblick well, in sec. 16, T. 9 N., R. 13 W., a plentiful supply of water is said to exist in sand at a depth ranging from 50 to 75 feet from the surface. It is possible that the large amounts of water found in wells along the foot of Rosamond Buttes is due to the proximity of the fault or flexure on which Willow Springs are located.

North of Little Buttes 1½ miles, in sec. 6, T. 8 N., R. 13 W., water of good quality is found beneath a 20-foot bed of clay at a depth of 50 feet in sandy layers containing clayey intercalations.

Vicinity of Rosamond.—From a point about 4 miles west of Rosamond southeastward to sec. 31, T. 9 N., R. 12 W., clay and coarse to medium sand with the clay slightly predominant occur from a depth

of 170 to about 220 feet. Near the bottom of these intercalated sands and clays are gravelly layers, which at some points carry weak artesian waters. From a depth of 150 feet downward both clays and sands are considerably indurated; limy layers, known locally as "hardpan" or "cement" are of common occurrence and offer considerable resistance to rapid drilling.

From section 31 northeastward the water-bearing gravelly beds thicken considerably and appear to pass into a coarse granitic sand like that found in a well one-half mile northeast of Rosamond, which encountered bedrock at a depth of about 300 feet. In this well the water rose 2 feet. The fact that within one-half mile of this hole a good artesian flow was encountered at a depth of 115 feet suggests that in this vicinity the north margin of the flowing area is against bedrock. Here, as farther west, considerable quantities of "cement" occur at depths from 100 feet downward. Surface water is encountered 5 to 15 feet below ground level and is quite plentiful. Nonartesian water also occurs at a depth of from about 30 to 75 feet in the region west of Rosamond. Artesian water in this vicinity has been struck at 115, 140, 185, 300, and 340 feet below the surface.

Vicinity of Redman.—Records available for six of the wells sunk near Redman's ranch indicate that in the region to the west and northwest sand and thin intercalated clay beds exist to a depth of about 225 feet. Some "cement" occurs with these sands and clays. North of the schoolhouse the amount of "cement" increases. At depths ranging approximately between 225 and 450 feet blue clay with little included sand or gravel has been found, and this impervious bed has held down the artesian waters found in cemented sand and gravel beneath it. There is also a free gravel carrying artesian water near the top of this clay at a depth of about 215 feet.

Northeast of Redman the conditions appear to be variable. A well about 1 mile south of Buckhorn Springs passes through clay with a small amount of sand to a depth of about 170 feet, below which heavy (and hence probably open) gravel carries a large flow of artesian water which appeared to have its greatest pressure at a depth of about 235 feet. Southeast of this locality, 2½ miles, the only clays encountered in a total thickness of 310 feet of sand were two thin beds at depths of 215 and 260 feet, respectively. The best artesian flow here was found at a depth of about 400 feet; at 250 feet a weaker flow is held down by a layer of limy "cement."

Surface water occurs at 6 to 15 feet, nonartesian water at 80 to 100 feet, and artesian water has been struck at depths of 130, 175, 210, 215, 225, 250, 550 feet.

Vicinity of Reid ranch.—The deposit of sand with some layers of clay and cement which has already been described as occurring west of Redman, extends farther and occupies much of the S. ½ of T. 8 N.,

R. 11 W., where it reaches to a depth of about 210 feet, but it thins toward the south where it is largely replaced by clay.

The wells about one-half mile north and for a distance of 3 miles east of Reids penetrate clay and intercalated cement layers to a depth of 300 feet. Sandy lenses are uncommon, but where found they usually carry artesian waters, as in one of the older wells on Reid ranch, in which six separate flows were struck. The confining beds for such waters appear to be in some places "cement" layers, in others clay. Only one sandy layer in this vicinity has so far been correlated in different logs. This is a thin lens at a depth of about 400 feet in the northeast corner of T. 7 N., R. 11 W.

Four miles south of Reid ranch two deep wells used for domestic supply penetrate sands and clay to a depth of between 80 and 115 feet. Below these sands and clays, clay and "hardpan" predominate to a depth of 565 feet. Though the water of these wells is artesian, the head is insufficient to bring it above the surface.

Surface water in this vicinity occurs at 5 to 15 feet. Artesian water is struck at 200, 250, 275, 300, 350, 375, 400, 450, and 570 feet below the surface.

Vicinity of Oliver Miller's ranch.—Intercalated layers of sand, clay, and cement, with the sand layers predominating, extend from the surface to a depth between 200 and 240 feet in the vicinity of Oliver Miller's ranch. Toward the southwest some clay and cement are interbedded with the sand, and eastward and northeastward the sand, with its included clayey layers is reduced to about 150 feet in thickness.

Beneath this sandy zone are clays with minor amounts of sand and "honeycomb cement." This term is applied throughout the region to a limy hardpan, either in clay or sand, which probably through the action of solvent water has been partly disintegrated and so rendered more or less cellular. In this condition it becomes, instead of the usual restraining agent, a free conduit for artesian waters. It is stated that some of the best flows obtained in Antelope Valley occur in such honey-combed zones. At a depth of between 380 and 450 feet, at Miller's house, soft sandy layers are found, and these form a portion of the zone in which the lower artesian waters are found.

Surface water here occurs at 5 to 20 feet and artesian water at depths of 145, 150, 240, 255, 285, and 450 feet.

Vicinity of Lancaster.—The logs of about 35 wells within a radius of 2½ miles of the center of Lancaster indicate in a general way the underground conditions. The records are most plentiful for wells in Lancaster (sec. 15), and if the logs are reliable they make it possible to know somewhat accurately the position and thickness of the various sand and clay and "cement" lenses.

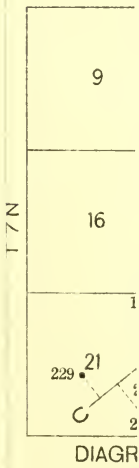
Wells in the southeastern portion of sec. 15 penetrate interbedded sands, clays, and cement layers, among which the sands appear to predominate, to a depth ranging from 150 to 235 feet below the surface. This arenaceous lens loses its character toward the north and northwest owing to the increase in the amount of clayey material which it carries. Thus several of the wells in the northwest quarter of town penetrate but three or four sandy layers within the first 200 feet of depth, aggregating less than 70 feet in thickness.

The log of Capt. E. M. Heaton's well, at the north edge of town, near the railroad, shows that but two thin layers of sand, less than 5 feet each in thickness, were penetrated in a depth of 220 feet; these thin layers represent the total thickness here of a lens which a mile to the south reaches, with its included clayey layers, a thickness of about 220 feet.

In Plate IV are shown a hypothetical section (B–B) across sec. 15 from the southeast corner to a point near the middle of the north side and a section (C–C) from a point near the center of sec. 21 northeastward to the north-central part of sec. 12. The positions of near-by wells have been projected to these lines and the generalized logs plotted. The deductions from the study of these logs as to the position of formations and water planes are shown. Data regarding the ground surface elevation of these wells are insufficient to fix their exact position, but as this difference in elevation is probably within 10 or 12 feet it has been neglected. The location of wells is shown on the sketch map of Lancaster and vicinity (fig. 5). Surface water near Lancaster varies from 5 to 50 feet below ground level.

Below the sandy zone in sec. 15 clay, with a considerable amount of cement but little sand, is found. Some of this "cement" is of the cellular or honeycomb variety and becomes the flowage zone for artesian waters. In the southeast portion of the section a water-bearing sandy layer lies at a depth of about 325 to 350 feet. Water-bearing sand and cement layers occur at depths of 230 to 275 feet in the north part of Lancaster.

Southwest of Lancaster the formation is clayey and contains evenly distributed cement layers. Several thin sandy layers occur at varying depths and these carry artesian water in most places. There is probably a more or less free connection between these sand lenses, as an artesian flow is encountered at a depth of only about 90 feet in this vicinity. The spring which rises at the center of section 21 is due to leakage of these artesian waters. The logs show that the sandy lens, between the surface and a depth of 235 feet in the southeast quarter of section 15, extends a mile or more toward the northeast, but includes in its upper portion more clay. In the clays



DIAGR

AT LANCA

U. S. GEOLOGICAL SURVEY

SECTION C-C. Position shown on diagram

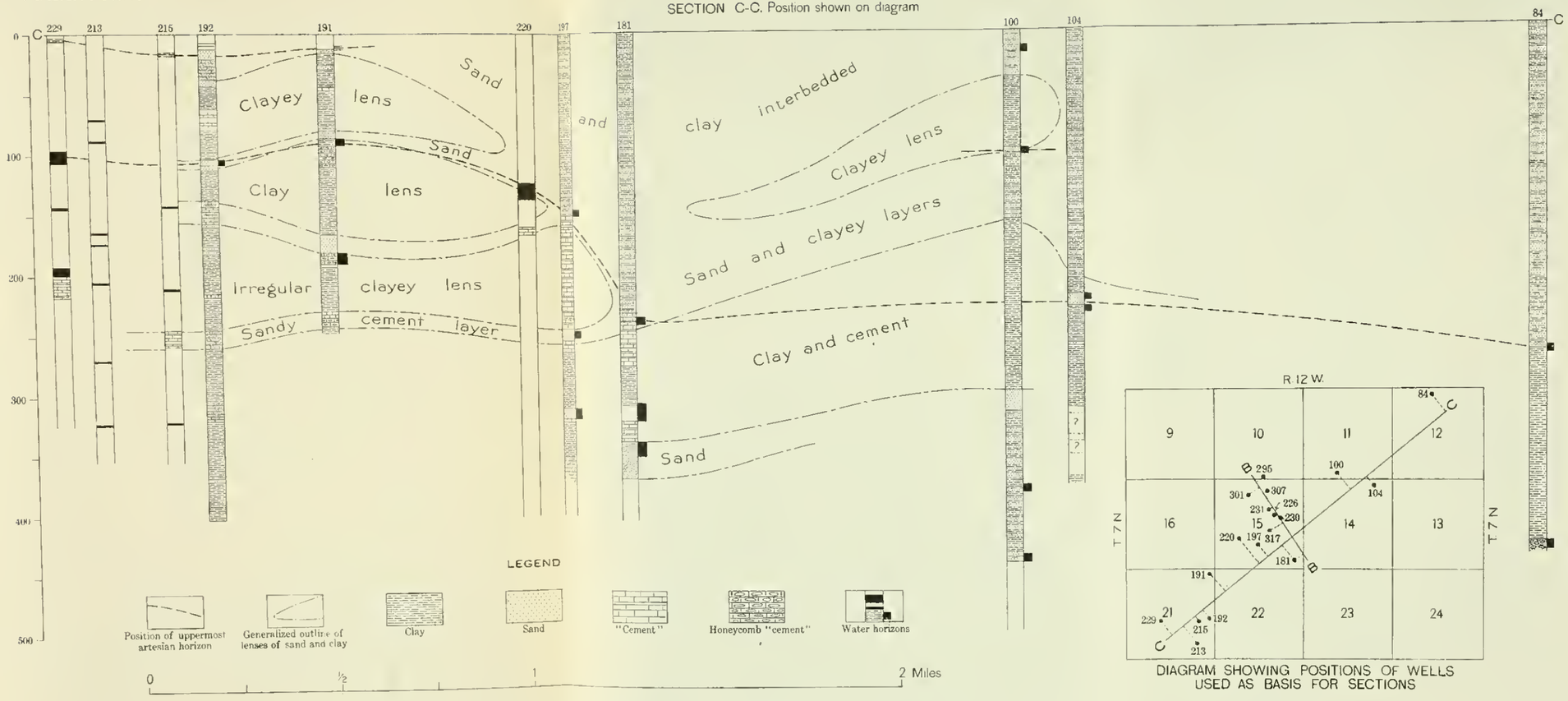
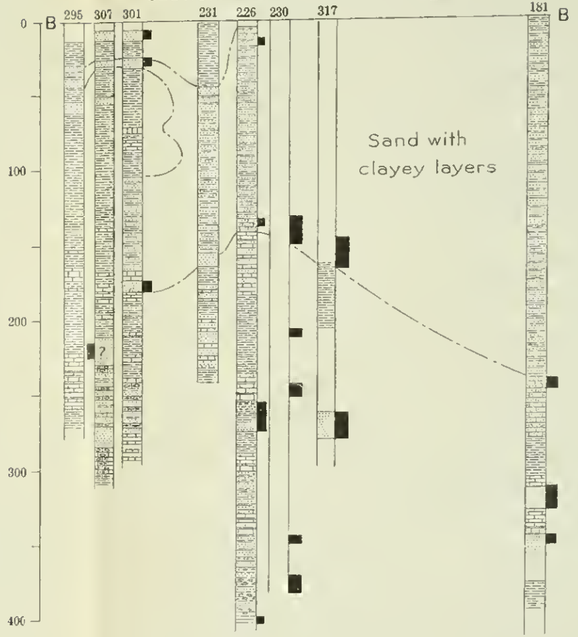


DIAGRAM SHOWING POSITIONS OF WELLS USED AS BASIS FOR SECTIONS

SECTION B-B. Position shown on diagram



WELL SECTIONS AND DIAGRAM SHOWING PROBABLE UNDERGROUND CONDITIONS AT LANCASTER AND VICINITY AS INDICATED BY WELL LOGS

THE NORRIS PETERS CO. WASHINGTON, D. C.

underlying this part of the sand lens, hardpans and cements are less important than southwest of Lancaster.

Depths to artesian water noted in several wells are 80, 100, 130, 150, 175, 200, 225, 250, 270, 325, 350, 375, 425, 440, 500, and 515 feet.

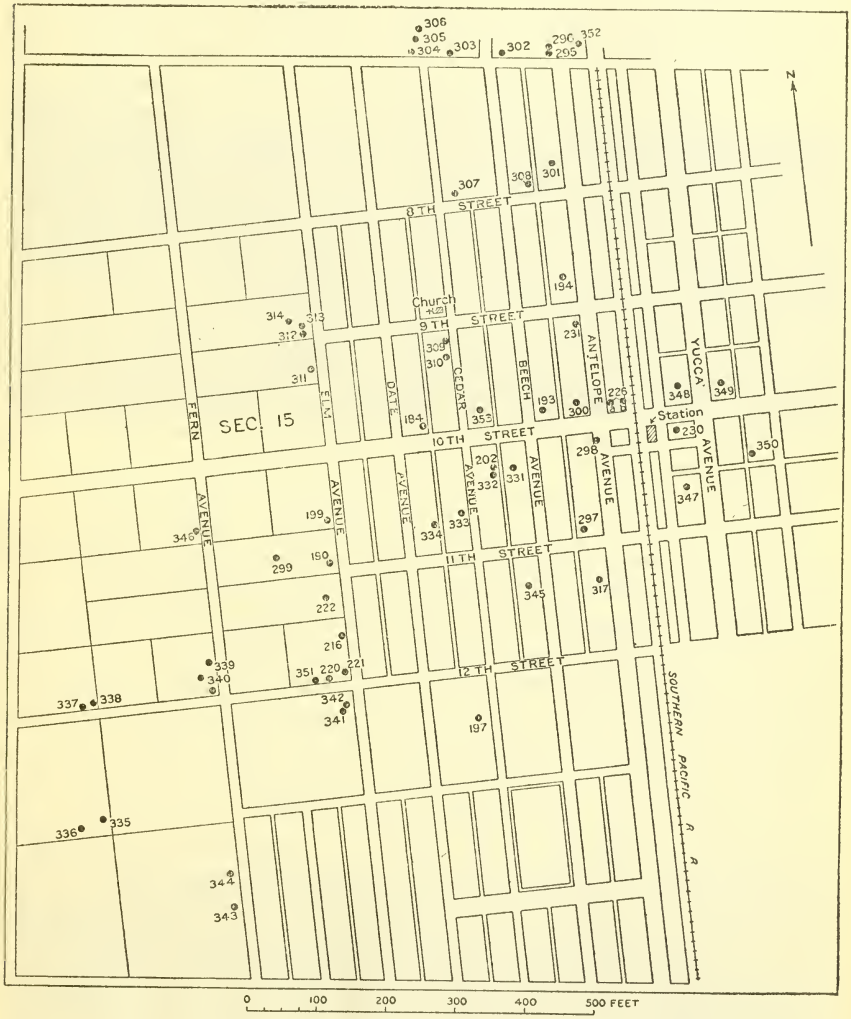


FIGURE 5.—Sketch map of Lancaster and vicinity, showing location of wells.

The irregularity of depth indicated by these figures makes it impossible to define the zones in which during future drilling water may be expected to occur, although the study of adjacent wells will often serve as a guide. The above figures are selected at random from records of wells within the neighborhood of Lancaster.

Vicinity of Coleman's ranch.—The logs of six wells are available in the region about Coleman's ranch, which is in sec. 10, T. 7 N., R. 12 W., and vicinity. These logs, though they indicate considerable variety in the strata penetrated, show that clay predominates, although there is much "cement," especially in the southwest portion of the section. A thin bed of sand is found just below the subsoil, and surface water occurs at a depth varying from 10 to 25 feet and is fairly well distributed. Clay with thin beds of "cement" and sand extends to a depth of between 75 and 100 feet and is underlain by a thin but continuous bed of sand which carries artesian water. Below this bed are clay and cement with only a minor amount of sand to a depth of about 350 feet, beyond which the logs do not extend. A zone of "honeycomb cement" at a depth of about 140 feet carries an artesian flow, as does also a similar layer in the clay, which slopes from a depth of 230 feet in the western part of the area to about 265 feet in the eastern portion. The most westerly log of the group indicates that in this direction the amount of sand is increasing. This group of logs indicates a greater regularity in the thickness and position of the deposits underlying section 20 than is usual in Antelope Valley; there is a corresponding regularity in the position of the artesian horizons.

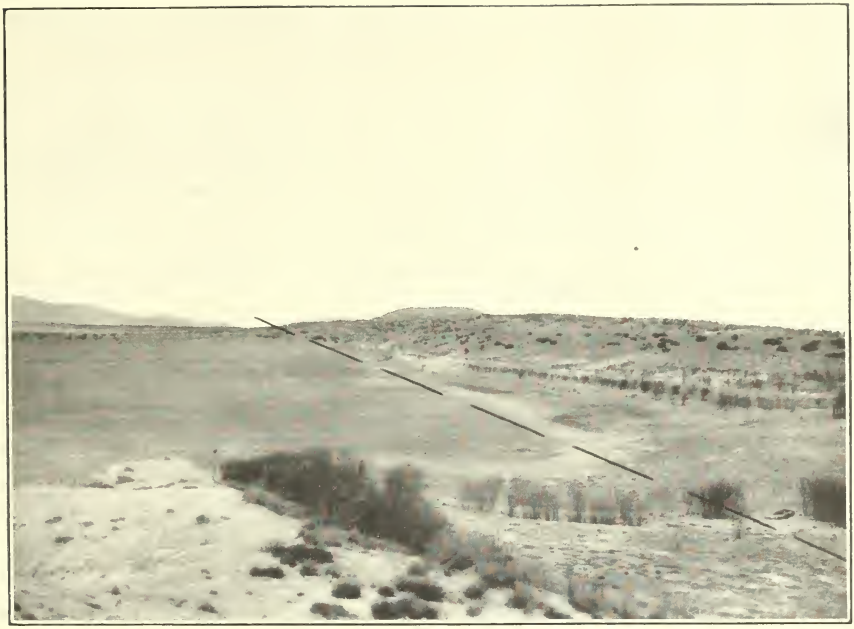
Surface water in this vicinity occurs at depths of 10 to 15 feet.

The upper artesian horizon is encountered at depths of 135, 150, 155, and 175 feet below ground surface, and the lower artesian horizon at 220, 230, 235, 265, and 320 feet below ground surface.

Vicinity of Esperanza.—Seventeen logs, some of them incomplete, of wells in Esperanza and vicinity, are available, and of these nine indicate that the deposits underlying the Post ranch and the property just south of it are mostly clay with minor amounts of sand and cement to a depth of between 150 and 250 feet. Definite beds of sand are not known to exist except at a depth of about 25 feet where a zone 8 to 15 feet thick carries surface water. Beneath the clays and usually associated with sand is a considerable thickness of "cement," much of which is cellular (honeycomb) and hence allows the free passage of artesian water. It is difficult to correlate beds in this part of the section, but a sandy uncemented zone is traceable at depths varying from 250 to 350 feet.

The logs of wells north of Post's ranch indicate a higher percentage of coarse sand from the ground surface to a depth of 225 feet, but below this the "cement" strata predominate, artesian flows occurring either in sands or "honeycomb cement."

The general sandy character of the upper portion of these wells persists toward the north, even as far as sec. 2, T. 8 N., R. 13 W., where sand with a minor amount of "cement" and clay exists to a depth of 200 feet, below which the quantity of "cement" increases.



A. PALMDALE RESERVOIR, LOOKING NORTHWEST.

Dash line indicates position of San Andreas fault. See page 33.

B. SAN ANDREAS FAULT TRACE NEAR ANAVERDE RANCH, LOOKING NORTHWEST.

Dash line indicates position of San Andreas fault. See page 21.

Surface water in the vicinity of Esperanza occurs from a few inches to 25 feet from the surface.

An upper artesian horizon is encountered at 135, 150, 160, and 185 feet below ground surface, the main artesian horizon at 215 and 260 feet below ground surface, and the lower artesian horizon at 285 and 310 feet below ground surface.

Vicinity of Palmdale.—Although the wells of this vicinity lie entirely outside of the area of flowing waters the logs are interesting in showing the distribution of the hardpans or "cements" encountered. North of Palmdale sands, some of them coarse, with considerable amounts of clay, contain only a few "cement" layers, but toward the south and southwest the amount of "cement," some of it apparently gypsiferous, increases remarkably. A reason for this may be found in the proximity of the structural area north of the San Andreas fault. (See Pl. V.)

Sandy layers in the clay and "cement" at depths of between 250 and 380 feet form the water conduits of this vicinity. No shallow water is found, but nonartesian waters occur at depths of 245, 265, 270, 340, 375, and 380 feet below ground surface. Although probably nonartesian, the water supply from the deeper zones is plentiful.

Vicinity of Oban.—Oban lies near the center of Antelope Valley, and as expected, the material penetrated in its vicinity is generally quite fine and clayey. A sandy zone at a depth of 15 or 20 feet, 3 miles west of the railroad, is found at correspondingly greater depths toward the east until at the center of sec. 14, T. 8 N., R. 12 W., it is between 90 and 100 feet below the surface. Clay, with a moderate amount of "cement" and a few sandy layers, exists to a depth of between 240 and 290 feet, where water-bearing sand and gravel are found. The logs of the deeper wells west of Oban indicate a continuation of the clay below this sand to a depth of 500 feet, where there is a stratum of water-bearing sand. Surface water in this vicinity is found at depths of 2 to 12 feet, and artesian horizons are encountered at 85, 140, 170, 215, 225, 240, 255, 270, 290, 370, and 502 feet.

Vicinity of Del Sur.—At Del Sur the formation is gravelly to a depth of 70 feet and nonflowing waters in fairly plentiful amount are found beneath a thin clay stratum about 55 feet lower.

Toward the west and northwest the beds are more clayey and contain small amounts of hardpan. On the west half of sec. 12, T. 7 N., R. 14 W., clay was penetrated to a depth of 100 feet, below which lay sand to a depth of 120 feet. Water is found here at a depth of 122 feet.

OTHER DATA.

The evidence offered by the well logs as to the underground conditions in the valley, is supplemented by that afforded by the gravels along the valley margin, which at a number of points are sufficiently

upturned to show the actual succession and arrangement of the material composing them. The exposures usually show the expected irregularity and interleaving of such deposits as would be found near the mouths of torrential streams, and these, except in their coarseness, form a good index of the conditions farther out in the valley. The best exposures of this nature are the upturned gravels of the Sand Hills of T. 9 N., R. 15 W., and the vertical and overturned gravels and sands along the San Andreas fault west of Palmdale.

DISTINCTION BETWEEN ARTESIAN AND NONARTESIAN WATERS.

Though it has been shown that all the underground waters of Antelope Valley have a common surface origin within its drainage basin, a few words are necessary to explain the distinction between artesian and nonartesian waters. By reference to figure 4, page 36, it is evident that water entering the valley deposits at *a* and percolating between confining layers towards the lowest part of the basin at *b*, will acquire a pressure head which increases with increase in depth of the water. The well logs indicate that water is commonly encountered at several levels, even in a single well, as in No. 213 of section C–C, Plate IV. Almost invariably in such wells the strength of flow follows the rule above stated. The waters near the surface therefore seldom rise appreciably, and usually not at all, when struck. Even where they may have acquired a slight head the loss due to the friction of the gravels, sands, or other materials through which the waters percolate may have completely nullified the pressure head. The term nonartesian is applied to all underground waters which do not show an appreciable rise when struck in drilling. They are usually confined, except near the margin of the valley, to the first 100 feet of depth.

The term "artesian" is applied to all underground waters which show an appreciable rise when struck, *whether or not the pressure is sufficient to produce flows at the surface*. The flowing area shown upon the map does not therefore, according to the above definitions, represent the total artesian area.

ARTESIAN WATERS.

FLOWING AREA.

Enough wells have been located in Antelope Valley to make it possible to outline on a map the area beneath which lie waters under sufficient head to flow over the surface of the ground when the confining materials are perforated, as by drilling.

This area occupies the central and lower portions of Antelope Valley, with a width north and south of about 13 miles and a length of about 25 miles, and contains over 240 square miles of territory. This estimate does not include a possible extension of the area under Rogers dry lake farther than has been drawn on the map. No conclusive data for or against such an extension are available. Topographically the conditions indicate that boring in or near the margin of this flat at points even north of Rodriguez might result in flowing wells, but the possible buried eastward extension of the Rosamond Butte scarp may act as a barrier to the northward flow of the artesian waters, as it does between Buckhorn Springs and Willow Springs.

Within this area there have been drilled during the past 25 or 30 years over 300 wells, most of which are flowing to-day. Many of these wells were examined during the winter of 1908–9, and much information was obtained, but for the following reasons this information is defective in certain respects, hence some of the conclusions drawn, especially regarding flow, must be incomplete and very general.

Some of the wells were sunk only as a means for obtaining patent to Government land; with the granting of such patents an owner might leave his land and well with little further improvement, and under such conditions the deterioration of the well, especially as to flow, is rapid. No information as to fluctuations or former flow of such abandoned wells is usually available except when the owner or driller can be found, and then the data are commonly not a matter of record.

During the winter season some of the wells are tightly capped and so are not available for measurement. Other wells rise below the water surface in reservoirs and so are inaccessible for flow tests.

Defects in drilling methods, some of them unavoidable, may result in procuring less than the maximum yield. A well casing may be perforated above or below the point at which the well penetrates a water-bearing stratum and consequently the well yields only a portion of its available flow. The accumulation of fine material within or around a perforated casing forms another source of trouble, resulting in a gradual decrease in the yield of the well. Again, if some of the gravels or sands penetrated above the artesian strata are sufficiently porous, the water during its rise to the surface, may waste away into these.

It may be stated, however, that if wells are carefully drilled, cased, and perforated, and the artesian zone is not too thin or too compact in texture, the strongest flows are to be expected in the lowest portions of the valley, that is, from the neighborhood of Oban eastward and a little north along the southern margin of Rosamond, Buckhorn, and Rogers dry lakes.

South of Redman's ranch 1½ miles several wells have been drilled which, judging from surface indications alone, should have yielded a good supply of flowing water. One of these, No. 70, was drilled to the depth of 612 feet, far enough to penetrate the lowest water-bearing zone yet found in the neighborhood, but the pressure was only sufficient to bring water to within about 6 feet of the surface. Such an occurrence indicates an unusual compactness in the material in the vicinity, or the existence of a buried dike of impervious clay or bedrock which isolates the strata penetrated by these wells from the main body of water-bearing beds in the valley. It is possible that the obstruction, if it is merely a thick lens of clay, does not extend to the bottom of the valley, in which case it is reasonable to suppose that water may be forced beneath it, so that by deepening the wells a free flow can be obtained. Should the drill, however, encounter what is certainly known to be bedrock, further expenditure would be useless, as artesian water in quantity for economic use is found only in the sediments lying on top of the bedrock floor of the valley.

NONFLOWING AREA.

Extending around the margin of the flowing area is a zone of indefinite width within which plentiful waters exist, but these waters, though artesian, have not sufficient head to rise and flow over the surface. The inner margin of this area is the line at which wells begin to flow, but the position of the outer boundary depends absolutely on the character of the water-bearing zone and the ground surface slope. In Antelope Valley it has been found that, with the value of the crops irrigated taken into consideration, pumping from a depth greater than 50 or 60 feet is at present unprofitable. To counterbalance the additional cost of farming due to this item, it is usually true that the soil of the nonflowing area is less alkaline and boggy than that within the flowing area, as it is better drained and, except near the flowing area, is not affected by the upward leak from the water-bearing strata.

VARIATIONS IN WATER LEVEL.

Information on this most important question of future development and conservation of Antelope Valley water supply is meager. Owners of wells have kept no record of seasonal fluctuations from year to year, so that the relations between rainfall and volume of artesian flow can not be established. The Geological Survey has no

records prior to those obtained in the winter of 1909, during the period of inactivity in the use of water. It is stated that for certain wells, generally those just within the margin of the flowing area, the summer flow is considerably less than the winter yield, and sometimes ceases. This is true of well No. 141, in sec. 8, T. 7 N., R. 11 W., which originally flowed 5½ miner's inches and when visited in the winter was flowing about half that amount. During the summer its flow ceases and its water is pumped. A well in Lancaster, near the Rockabrandt place, flowing 12.5 miner's inches when visited, is stated to flow but 8 inches in the summer. The flow of wells on the Coleman place at the margin of the flowing area near Lancaster is reduced about half during the hot season. On the other hand, a well (No. 249) in sec. 14, T. 7 N., R. 13 W., also near the margin of the flowing area, is very slightly affected. A well on M. H. Cheney's place, in sec. 2, T. 7 N., R. 12 W., flowed 14 inches when visited, and is stated to flow but 10 inches during the summer. These few examples cover such information obtained regarding seasonal fluctuations as is sufficiently definite to include here, but it may be stated that there is a natural reduction in the pressure head during the period of high evaporation. How much of this is due to lowering of the water table through evaporation and inadequate replenishment and how much to increased use of the water is unknown.

Fluctuations of a less extended nature than those just described are due to pumping. It has been observed that the flow of wells adjacent to the pumping plants is usually reduced during the operation of the plants, but the normal supply is resumed when the plant is shut down. Such close connection between wells is indicative of a free percolating medium between them. Uncapping of wells at some points causes a reduction in the flow of adjacent wells.

ARTESIAN SPRINGS.

Artesian water within Antelope Valley finds natural outlets in a number of springs, including Buckhorn Springs, a spring southwest of Lancaster, Indian Springs, and Willow Springs.

Buckhorn Springs.—The several outlets which compose the Buckhorn group of springs are in secs. 27 and 28 of T. 9 N., R. 10 W., and are visible from a distance as low, grassy mounds in the flat brushy region between Buckhorn and Rogers dry lakes. The most typical of these outlets is near the cabin in section 28. The water bubbles up strongly from the bottom of a small depression at the apex of a low mound, and brings with it a considerable quantity of clean white granitic sand which forms a small crater-like heap just at the point where the water issues. The quality of this water is comparable to that of the neighboring artesian wells, and this, with the strong

upward current of the springs, suggests an identity of origin. It is only necessary to explain their leakage upward from beneath the impervious clay, which is probably the confining agent in this low portion of the Antelope Valley, and the reason for the existence of the springs becomes apparent.

Two explanations are offered: Either the local interleaving of water-bearing lenses at this point has permitted the free upward leakage or flow of otherwise confined artesian water, as shown in *a* of figure 6, or else the fault which is believed to exist along the south slope of the Rosamond Buttes, described on page 21, has deformed and fractured the water gravels lying beneath the surface as indicated in *b* of the figure, and so furnished a conduit for the deep artesian waters. The total flow of Buckhorn Springs is now impossible to measure and difficult to estimate. It may amount to about 20 miner's inches.

At the time of the San Francisco earthquake the writer observed temporarily active fountains or springs produced in just this manner

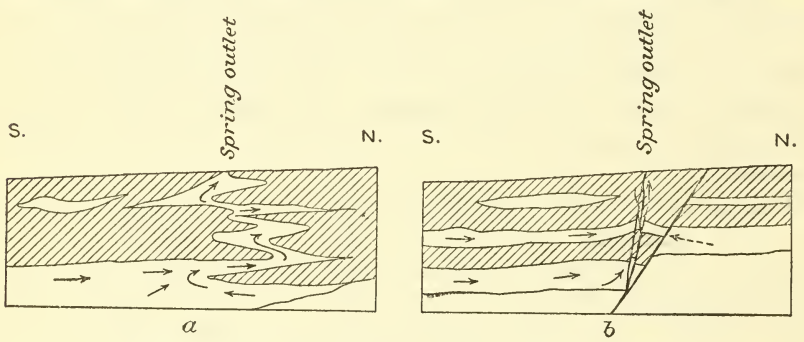


FIGURE 6.—Diagrams showing possible origin of Buckhorn Springs.

along the bed of Coyote Creek in the Santa Clara Valley (of the north), where fractures produced by the earthquake penetrated deep enough into the valley filling to become conduits for artesian water.

Spring southwest of Lancaster.—The spring southwest of Lancaster (see p. 40) which is now hardly more than a seep, is located almost at the center of sec. 21, T. 7 N., R. 12 W., on a little grassy mound. Its water contains 182 parts per million of dissolved solids, thus agreeing closely with the water of flowing wells just a few hundred feet north. The logs of wells in the vicinity show that artesian water is found at depths less than 100 feet from the surface and that it occurs at several horizons below the uppermost. These facts indicate very clearly that the water-bearing zones have free intercommunication, and that just at the spring the conduits reach the surface. The condition is clearly that indicated diagrammatically in *a* of figure 6, for Buckhorn Springs.

Indian Springs.—The group of outlets known as Indian Springs, located in the SE. ¼ of sec. 14, T. 9 N., R. 12 W., was hastily examined. It lies just at the foot of the steep south face of Red Butte, which appears to be a part of the scarp of the Rosamond fault. Like Buckhorn Springs, the springs are believed to rise either along the fault plane itself or through fractures in the valley deposits produced in connection with the faulting.

The amount of flow here is unknown, but is sufficient for use locally at near-by mining camps.

Willow Springs.—Seven or more strongly flowing springs all lie in the S. ¼ of sec. 7, T. 9 N., R. 13 W., and have a combined flow sufficient to irrigate about 33 acres lying to the south of the points of outlet.

Though these springs have long been known, they have been extensively used for irrigation only within the past few years.

Mr. E. M. Hamilton, to whom the property now belongs, has, in connection with many other improvements of a substantial nature,

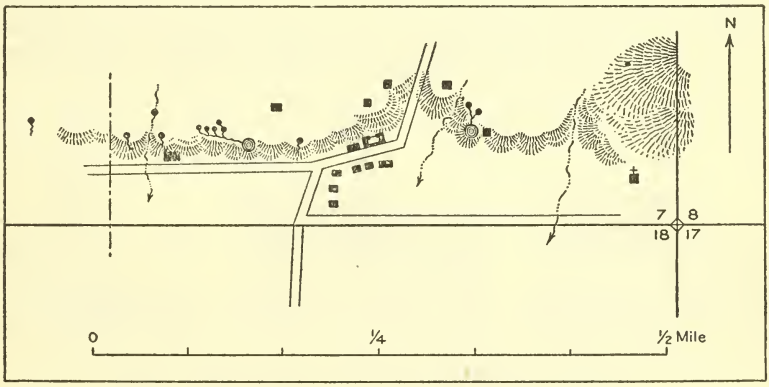


FIGURE 7.—Sketch map of Willow Springs and vicinity.

constructed cement storage reservoirs at two of the springs, and from these the water is conducted to orchards and fields in the eastern portion of the property. The general arrangement of the springs is shown in the accompanying sketch map.

Their alignment upon and parallel with the scarp extending westward from the butte northwest of the schoolhouse is a striking feature and indicates some relation between the two. The evidence for the existence of a fault coincident with the south face of this scarp has been presented, but its influence on the production of flowing waters along and near the crest of the ridge remains to be explained. There are three possible sources for the waters of Willow Springs. They may be (1) a portion of the artesian supply of Antelope Valley, (2) the underflow of a stream draining the higher region to the north, or (3) they may flow from the buried bedrock which is a part of the buttes to

the east. If from the first source, the waters rise along planes of weakness developed along a flexure or fault of which the scarp is the topographic expression, as in *a* of figure 8. If of the second class, the flexure produced by the faulting, or possibly even the edge of the upthrust bedrock block, may act as a submerged dam, as in *b*, and so bring southward-flowing waters to the surface at the apex of the dam thus created. There is little evidence for supposing that all of these waters flow from the bedrock itself, but as there is the possibility that this may be a contributory source of water the diagram at *c* has been drawn to express graphically such a condition.

The acceptance of the first hypothesis requires the assumption of flowing artesian water in a portion of the Antelope Valley where none as yet has been found. As no deep wells have been bored in the vicinity of Willow Springs, it is quite possible that artesian water may yet be found in the region south of the scarp. For this reason the margin of the flowing area upon the map has been left indefinite near Willow Springs.

Much of the water flowing into the lowland east and southeast of the Tehachapi Range, but north of Antelope Valley, would enter the

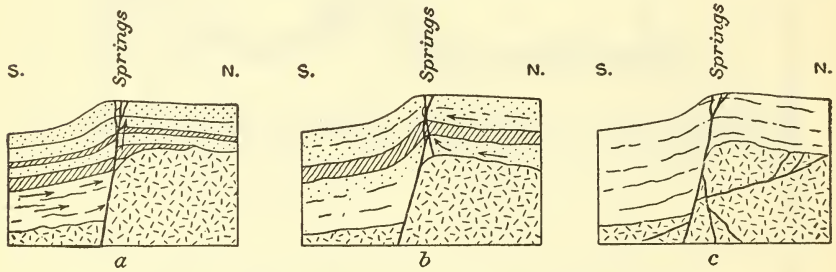


FIGURE 8.—Diagrams showing possible origin of Willow Springs.

gravels of the depression and seep southward toward Antelope Valley, as the buttes and ridges near Soledad Mountain would offer a definite resistance to further eastward flow.

It is not unreasonable to suppose that the springs are due to overflow of ground water from the north against a buried dam such as that existing at Willow Springs. It would be expected under such conditions that the largest flows would occur in the gulches draining the ponded area behind the dam, yet the deepest gulch answering these requirements is that just east of the schoolhouse at Willow Springs; and this was entirely dry when visited in November, although immediately adjacent to a plentiful flow from the springs. No explanation for this has been found.

The following table condenses the available facts in regard to the springs:

Water supply at Willow Springs.

No.	Locations.	Flow.	Total dissolved solids.	Remarks.
			Parts per million.	
1	Northeast of hotel	2,700 gallons per hour	312	Used for irrigation and bathing; flows into a cement pool.
3	In gulch west of house	Seepage		This is called "borax spring" and is not used.
4	West of fence	Slight		Temperature 69°.
6	At west reservoir	360 gallons per hour		A group of 7 or 8 springs which are led into a single channel and thence into a circular cement reservoir of 60,000 gallons capacity.
8	East of west reservoir			Used for domestic purposes.

A number of shallow wells have been sunk at various points along the line of springs, and water of fair quality is obtained from them. None of these wells flow over the surface, although they appear to be plentifully supplied with water.

The chemical character of the Willow Springs water is given in the table on page 57.

The springs which rise along the scarp to the west of Willow Springs as far as sec. 11 of T. 9 N., R. 14 W., are similar in character and origin. Of these, Bean Spring, which includes three of the larger flows, is the most important.

NONARTESIAN WATERS.

DISTRIBUTION.

The nonartesian waters include most of the shallow ground waters in the valley, and so far as known, all the ground waters near the margin of the valley. These waters have a source identical with that of the artesian supply; their difference lies in the fact that the nonartesian water possesses no appreciable head.

In portions of the valley where the nonartesian water is found in considerable quantity and of fair quality it is usually the result either of upward leakage from underlying artesian zones or of accumulation of surface water above an impervious layer. Within the flowing area of the valley, waters, higher in dissolved solids and usually in rather small quantity, are found at depths ranging from a few inches to a number of feet below the surface. The position and quantity of these waters are delicately adjusted to the capillarity of the soil, the humidity of the atmosphere, the upper limit of percolation through the soil, and to leakage from the underlying artesian zones. If this upward leakage reaches a level, for example, of 25 feet below the surface, capillarity in a soil of average texture may bring it 10 or 12 feet nearer the surface. If the depth thus reached is too great to be within the influence of evaporation, a plentiful

supply of fairly good water may be expected, but should the level be sufficiently near the surface of the ground the mineral content will become concentrated because of evaporation and the water supply will be more scanty. These conditions may account for the differences in quality and quantity noted in the shallow wells of the Antelope Valley.

NONARTESIAN SPRINGS.

Springs of the nonartesian type have not been found in the valley proper, but they occur between the two larger hills of the Antelope Buttes northeast of Fairmont and among the buttes east of the valley.

Springs of Antelope Buttes.—Water rises along the stream course in the E. ½ of sec. 31, T. 8 N., R. 14 W., at a couple of points, and after flowing a short distance toward the north again sinks beneath the gravels of the gulch. It is probable that these springs represent underflow from the region lying to the south, which has been brought to the surface because of the interruption offered to its flow by the bedrock of the buttes. Another explanation, however, may be that the waters percolating through the tuffaceous and gravelly upturned beds to the west strike the resistant underlying granitic bedrock, and so reach the surface at the contact between these porous and impervious formations. Reference to figure 9, which represents a cross section of the Lovejoy Buttes, will make clear conditions similar to those just described.

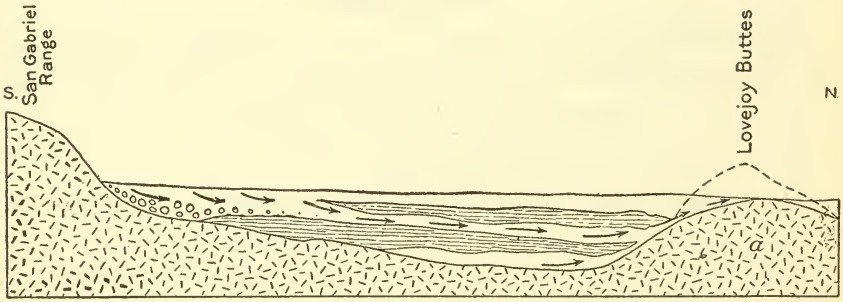


FIGURE 9.—Diagram showing the origin of Lovejoy Springs.

Lovejoy (Croswell) Springs.—The Lovejoy Buttes, extending east and west through the middle of T. 6 N., R. 9 W., serve as a practically impervious dam to a large part of the waters percolating northward through the gravels of Big Rock Creek wash, and the Lovejoy (Croswell) Springs are excellent examples of springs whose origin is directly traceable to the overflow of dammed up ground waters.

The lowest gap across the buttes extends northward between the two main groups as a deep gorge, which appears to have been originally a channel for one of the distributaries of Rock Creek. It

is natural, therefore, that the underflow of the creek has found an outlet at the upper end of this gorge in springs which represent the emergence of the dammed up ground waters from the south which have been forced over the bedrock of Lovejoy Buttes much as shown in figure 9. An indication of the proximity of these ground waters to the surface in the region just south of the springs is found in the deposits of alkali there noted. It is believed that water, possibly artesian, may exist here in quantity and quality sufficiently satisfactory for economic use. Lovejoy Springs are at present used for stock, though indications of plowing and the remnant of a dam below the springs suggest that the water may have been used at some time in a very small way to irrigate a narrow strip of grain or garden.

Moody Springs.—Near the center of the north line of sec. 15, T. 6 N., R. 8 W., are Moody Springs, used by stock and the few travelers in the region. Though fairly palatable the water contains a much higher quantity of mineral matter than the artesian water of Antelope Valley.

The reasons for the existence of this spring are similar to those for Lovejoy Springs, except that the obstruction to the underflow, a low, partly buried ridge of granitic rock, is not prominent. It extends across the course of the underflow in a northeast-southwest direction. It is possible that some water of an inferior quality may be obtained by wells in the flat east of the spring.

BEDROCK SPRINGS.

At many points in the foothills of the ranges inclosing Antelope Valley are springs which flow directly from the bedrock itself. They are not of great economic importance, but those which were noted in the course of the field work connected with the preparation of this report are briefly described.

Springs on southwest slope of Tehachapi Range.—Springs are plentiful on the tributaries of Little Cottonwood Creek and usually escape from channels worn in the limestone of the metamorphic series so prominent in the Tehachapi Range. They have in the aggregate a considerable but unmeasured volume and must conduct some water into the gravels of this portion of Antelope Valley. They carry calcium in solution and have at certain points built rude low terraces of calcareous tufa below their outlets. Such a spring near the forks of Livsey Creek contains over 600 parts per million of dissolved solids.

The spring which supplies Knecht's ranch with water for domestic uses issues from granitic and metamorphic rocks, hence yields water that is much softer than that of the Livsey Creek Spring.

Gerblick Spring.—In the NW. ¼ of sec. 16, T. 9 N., R. 13 W., just west of Mr. Gerblick's house, is a spring which flows from the granite.

The spring is said to fluctuate little in volume and its low mineralization, about 180 parts total dissolved solids per million parts of water, suggests a bedrock origin. In a nearby mining shaft a flow of water estimated at 7 miner's inches was encountered on a contact between "granite and porphyry," at a depth of 110 feet, and this water is believed to be a part of the supply tapped by the spring. The faulted condition of the bedrock in this vicinity probably affords a cause for this and other springs along the scarp between Gerblick's and Indian Springs. It is conceivable that artesian waters in gravels lying to the south of Gerblick's may have found less constricted conduits along fault fractures in the bedrock than through the imperviousbeds of clay or cement directly above the artesian zone. Such a condition is expressed in figure 10, in which *a* is the point of outflow and *b* the point of inlet for the water flowing upward through the fractures, represented by heavy black lines.

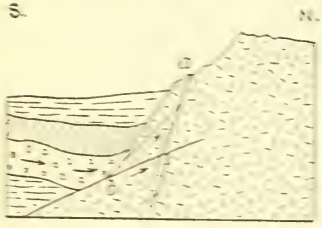


FIGURE 10.—Diagram showing possible origin of Gerblick Spring

Barrell Spring.—Barrell Spring, in sec. 7, T. 5 N., R. 11 W., has been a watering place for many years. It was not visited, but reports indicate that the water is apparently a seepage from the bedrock alongthe fractured zone of the San Andreas fault.

Newquist ranch springs.—The springs at Newquist ranch, on the slopes south of the Palmdale reservoir, flow from an intrusive in the granitic rocks of the San Gabriel Range at a considerable elevation, and furnish sufficient water for domestic use. The water contains about 270 parts of solid matter per million.

Springs on Mrs. Dahl's ranch.—In sec. 13, T. 6 N., R. 13 W., on Mrs. Dahl's ranch, are springs that yield sufficient water for domestic purposes. The water is conducted to the house from a tunnel in the granitic and schistose foothills. A test of this water made at the faucet shows a mineral content considerably greater than 600 parts per million.

A spring in sec. 10, T. 6 N., R. 13 W., whose water is of somewhat better quality, has been used two years for irrigating a small garden patch.

Spring at Keeves ranch.—At Keeves ranch, in sec. 14, T. 6 N., R. 13 W., the springs furnish water of the same general character as that of neighboring springs. It is probably somewhat softer than that in section 10, and rises at the foot of a knob which at a distance resembles serpentine.

Spring at Simmons's ranch.—The water of the spring at Simmons's ranch rises in sec. 5, T. 6 N., R. 13 W., and is piped to the ranch house in sec. 32 of T. 7 N., R. 13 W., where it is used for domestic

purposes. It contains about 550 parts dissolved matter per million and is palatable.

Other bedrock springs occur in the neighborhood along the north slope of Portal Ridge, but nothing is known of the quality or quantity of their waters.

Mulford (?) Spring.—A spring believed to be in sec. 31 of T. 7 N., R. 13 W., flows about 50 gallons per hour in the winter and somewhat less during the summer. It contains a low proportion of solid matter and is comparable in quality to the artesian waters of the valley.

Springs at Geier's ranch.—The springs at Geier's ranch flow from granitic bedrock on the steep slope at an elevation of 2,940 feet just south of the ranch house in sec. 27, T. 7 N., R. 14 W. The water contains less than 200 parts per million dissolved solids and is probably as good as any of the bedrock waters along the south margin of Antelope Valley.

Neenach water supply.—The settlement at Neenach and a number of the adjoining ranches obtain a supply of water from springs in the Sierra Pelona in the NE. ¼ of T. 7 N., R. 17 W. The water of five springs is gathered through 1½-inch and 2-inch pipe lines and conducted to catch basins, thence through 4-inch, 3-inch, and 2-inch pipe successively, a distance of 7 miles to Neenach. A constant though variable supply is thus obtained which furnishes practically all the water for settlers in the main valley in this vicinity.

The plant was installed 15 years ago by Henry Hatch, of Los Angeles, at a cost of $6,000, and the above information was obtained through his courtesy.

Spring at La Liebre ranch house.—The water of the spring at La Liebre ranch house is hard, but its location and free flow make it one of the noted springs of the region. The flow amounts to 1,500 gallons per hour, but so far as could be learned none of this water is used for irrigation, though the spring is admirably located at the head of an irrigable tract of alluvial land.

CHEMICAL CHARACTER OF GROUND WATERS.

ORIGIN.

All the waters found within and adjacent to Antelope Valley had, at the time of their precipitation, the purity of rain water, and whatever chemical differences they have since acquired are due to their solvent action on the various minerals with which they have come in contact during their passage over and through the rocks and soils. It is therefore evident that the character of the water is related to the chemical character of the rocks of the valley and its rim.

In order to study the character of the waters of the valley in a general way, analyses were made of several waters whose electrical

resistance had previously been determined by means of a modification of the Wheatstone bridge—an instrument devised in accordance with the principle that the resistance offered to the passage of an electric current through water decreases as the proportion of dissolved solids in the water increases. The resistance as actually measured is reduced to an equivalent resistance at a standard temperature of 60° F., and by the use of a curve based on actual analyses and corresponding bridge tests, resistance may be reduced to proportionate parts of solid matter in a given quantity of water. Although the electrolytic method of determining the quantity of dissolved solids in a water is not accurate, it furnishes a simple and rapid means of distinguishing relative amounts of total solids with sufficient correctness for many purposes. All determinations for the Geological Survey are stated in parts of solid matter per million parts of water.

Waters which contain 150 parts or less of solid matter per million may be considered excellent; those containing more than 500 or 600 parts per million are inferior; those with intermediate amounts represent ordinary types of natural waters.

The waters in any region may differ considerably in quality, although the explanation may not be obvious. Such differences may be due to a variety of causes, among which may be mentioned the presence of soluble mineral matter along the course of the underflow, different water temperature with consequent different solvent power, and concentration of water due to evaporation. This last cause is usually important only in regions where the ground waters are ponded near the surface so that free circulation is impeded and evaporation induced. It is probable that much of the "caliche" or "cement" (hardpan) found beneath portions of Antelope Valley and already referred to in discussing the well logs (pp. 38–39) has been formed as a result of deposition from percolating waters at a period when the horizon at which they occur was at the surface. The "honeycomb" cement may be a result of partial re-solution of material already deposited. It is usually an excellent conduit for artesian waters, while the more compact "cement" is equally effective in confining the waters to less impervious layers of sand and gravel.

ANALYSES.

The following table shows the chemical character of six representative waters in the Antelope Valley:

Analyses of Antelope Valley waters.

[Walton Van Winkle, analyst. Quantities in parts per million.]

Wells.	Owners.	Locations.	Total dissolved.	SiO_2.	Fe.	Ca.	Mg.	Na+K.	CO_3.	HCO_3.	SO_4.	Cl.	NO_3.
270	Morford, S. J....	14–18–12	330	52.0	0.84	5.1	6.2	102	19.0	196	54	65	0.64
265	Mosby, John.....	26– 9–12	460	45.0	.86	5.7	1.8	154	9.6	325	55	29	.0
253	Veysette ——....	22– 7–13	267	39.0	.05	36.0	12.0	41	.0	146	31	18	30.0
146	Hahn, B. W.....	8– 7–11	161	39.0	.07	23.0	3.7	25	6.0	96	25	5.5	1.7
51	Post, C. N.....	10– 7–13(?)	283	16.0	.08	40.0	7.0	54	.0	176	44	25	7.0
(a)	Hamilton, E. M..	7– 9–13	312	25.0	.25	44.0	9.1	54	.0	155	101	19	.....
	Average for 6 waters...	.....	302.2	36.0	.36	25.63	6.63	71.66	5.77	182.33	51.67	17.17	6.56

[a] Willow Springs No. 1.

Where mineralized water issues at the ground surface, evaporation usually results in the deposition of a portion of the mineral content in crusts upon or as cementing material in the adjacent surficial deposits. Examples of such travertine deposits are found on the southwest slope of the Tehachapi Range, in front of Bean Springs and Willow Springs, and at other points where springs issue. None of the artesian wells noted carry sufficient mineral matter to leave a deposit on the casing. Some of them, however, contain sulphur enough to produce a yellowish deposit on the algæ usually found inside the casing of wells which have fallen into disuse.

FORMATION OF ALKALI.

Over a portion of Antelope Valley, especially in the lower part of the area of flowing wells, the surface of the ground is more or less spotted with incrustations of "alkali." Three varieties of this are found; one, a "white alkali," is sodium sulphate; another, called "black alkali," from its darkening effect on vegetable tissue, is sodium carbonate; and the third is sodium chloride or common salt. Of the first two, the more injurious to plant life is the black alkali, as it has a tendency to hydrolize and form the harmful NaOH, which has a disintegrating effect on organic tissue. Except where underdraining and flushing of the alkali-ridden soils can be resorted to the most effective method of disposing of the black alkali is by the use of gypsum as a fertilizer; by this means the harmful salt is changed to the less injurious sulphate.[1]

Incrustations of alkali are seldom found except where the water plane is near the surface. Where this is the condition the effect of capillarity is to gradually raise the water to the surface and with it the dissolved mineral matter. As evaporation takes place this mineral matter is precipitated, and hence at and near the surface forms an incrustation which yields readily to the solvent action of

[1] Waring, G. A., Geology and water resources of a portion of south-central Oregon: Water-Supply Paper U. S. Geol. Survey No. 220, 1908, pp. 75–76.

rain or flowing surface water and so may be distributed to other portions of the surface. A very effective agent for the distribution and increase of surface alkali in Antelope Valley is the waste from uncapped artesian wells, and so long as the illegal practice of allowing such waste is persisted in, the natural accumulation of alkali at the surface will be increased. The following analyses show the composition of white incrustation from the margin of pools whose water is saturated with sulphates, chlorides, and carbonates of sodium. The pools are near Buckhorn Springs and the data are available through the courtesy of E. V. Bray, of Berkeley, Cal., who states that large efflorescent crystals of sulphate of sodium occur in the mud of the vicinity.

Percentages of sodium carbonate in incrustations from margin of pools near Buckhorn Springs, Cal.

[Data by E. V. Bray.]

No. of sample.	Localities.	Per cent of Na_2CO_3.
1	Fluffy stuff, west pool	21.7
2	Surface crust, east pool near pit	37.7
3	Extreme north shore of east pool near pit	7.67
4	North end of big pool	15.33
5	Crust sacked in shed (well dried)	44.96
6	Crust east of east pool	30.14
7	Hard crust in west pool	48.54

The remaining percentage of each of these samples is a mixture of sulphates and chlorides.

QUANTITY OF DISSOLVED SOLIDS.

The determinations of total solids for the Antelope Valley waters indicate a range from somewhat less than 150 parts to over 600 parts of solid matter per million parts of water.

The broadest distinction as to mineralization is that between the artesian and most of the nonartesian waters. Of these two groups the former, with a very few exceptions, are low in dissolved solids and rank well among artesian waters of the Pacific coast. Some of the nonartesian waters, especially in wells near the margin of the valley, are poorer and at some points, particularly along the San Andreas fault zone, contain large quantities of mineral matter in solution. The waters of bed rock springs also show a considerable range in mineralization, as already indicated.

In and near the flowing area the best water, that containing 150 to 200 parts of dissolved solids per million, is found in most wells within an ill-defined area extending from the southwest portion of sec. 20, T. 7 N., R. 12 W., eastward and north through Lancaster and thence eastward along the N. ½ of T. 7 N., R. 11 W., and the southern part of T. 8 N., R. 11 W.

Water containing 200 to 250 parts of dissolved solids per million parts of water is found between Lancaster and a line swinging north and south about a mile east of Esperanza. From Reid's ranch eastward and northeast of Redman's ranch, thence in a broad zone westward toward Oban, and thence southwest toward east Esperanza is an indefinitely bounded zone in which waters contain 200 to 250 parts of solids per million parts of water.

Water in the remaining portion of the area of flowing wells, which includes the neighborhood east and north of Redman's ranch and the vicinity of Esperanza besides the broad region between Rosamond and Rogers dry lake and between Rosamond and Esperanza, usually contains slightly higher percentages of solids although not enough to affect its potability, for all of the water obtained from flowing wells is of excellent quality.

Data as to the mineralization of waters from shallow and other nonartesian wells are scanty, but in general such waters, except those found well out in Antelope Valley, contain 250 parts or more of solid matter per million parts of water. The general rule, that the quantity of dissolved solids decreases toward the valley margin holds good. Exceptions to this rule have been noted at Palmdale and Old Palmdale, where four of the six wells examined contain water that is moderately mineralized, and at the Barnes ranch in sec. 14, T. 8 N., R. 17 W., where the water contains between 200 and 250 parts per million of solids. In general the shallow water developed at several points along the foot of the Rosamond Buttes between Rosamond and Willow Springs is, perhaps because of the proximity of the flexed or faulted zone already described, of better quality than that in wells in alluvium along the north slope of Portal Ridge between Del Sur and Palmdale.

HYGIENIC CONDITIONS.

Except where shallow waters may have been contaminated by alkali or drainage from stables or outhouses, the ground water of the main Antelope Valley may be considered free from injurious quantities of organic or mineral matter. In some of the wells near the foothills, however, the amount of dissolved mineral matter may be sufficiently high to prove deleterious, although little complaint is heard of bad effects among those who have been in the habit of using the water.

FALLACIES REGARDING UNDERGROUND WATERS.

SUPPOSITIONAL SOURCES.

It may be considered beyond the province of an official report to give space to the consideration of the various untenable theories advanced from time to time regarding the source and inexhaustibility of the artesian waters of Antelope Valley. It is natural that the

sight of a flowing or spouting well, especially in an arid region, should induce speculation as to the source of the water and as to the reasons for its flow; it is also natural that the simplest explanation therefor should be overlooked in the search for some more dramatic if less likely reason. In order that the reader may not take too seriously some of the fantastic theories locally advanced as to the origin of the well waters of the valley, a brief discussion of some of them has been included with the report.

It is held by some that a free underground channel extends from the lower Owens River or from Owens Lake to the artesian basin of Antelope Valley. In support of this it is contended that Owens Lake has no visible outlet and the great quantity of water brought into the lake by the river has no escape except by underground leakage. Where, it is asked, can this water escape to if not into Antelope Valley? In answer, it need only be pointed out, first, that Owens Lake is strongly saline because of an evaporation sufficiently high to remove annually more water than it receives; second, that in the hundred-mile stretch of country between Owens Valley and Antelope Valley there are many bedrock masses, such as buttes and desert mountain ranges, which would absolutely prevent percolation underground between the two points; and, third, that the existence of a free underground channel over 100 miles long is utterly unproved, and no features observed in the region point to its possibility. So far as Owens Lake is concerned the high salinity of its waters proves the absurdity of considering it as a source of the pure waters of the Lancaster region.

A much less fantastic though still untenable theory to account for the head developed in waters of Antelope Valley assumes that the water which falls as rain or snow in the upper portion of the mountains, finding its way into the artesian basin through fractures and channels in the bedrock, becomes in this way the artesian supply of the valley. It is quite true that a small portion of the ground waters may be fed into the basin in this manner, but the close-grained, impervious, granitic mass of the San Gabriel, San Bernardino, and Tehachapi ranges offers a most effective barrier to percolation, and the very small amount of precipitation in the region north and east of Antelope Valley indicates that correspondingly small amounts of water enter the generally impervious rocks there. It is evident that a still smaller part of such absorbed water would ever reach the valley.

In both of these theories of origin for ground waters, the most natural sources, i. e., streams debouching into the valley from its marginal ranges, are entirely overlooked. It is argued without sufficient knowledge of the facts that the amount of water which these streams introduce is insufficient to account for the abundance of water in the gravels beneath the valley floor, but apparently the very

important factor of time is neglected. It must be remembered that for hundreds of centuries these streams have intermittently carried unmeasured quantities of water into the gravels where, sinking beyond the reach of evaporation, they have accumulated and filled the rock basin to the level of the lowest point in its rim.

USE OF THE "WATER WITCH."

In Antelope Valley, as elsewhere, believers in that curious anachronism, the old "water witch" superstition, are still occasionally met. It is difficult to give to this belief sufficiently serious consideration to discuss it in an official report. At best some of the operators of the device may be self-deluded, but by far the greater number are no doubt simply shrewd charlatans who have some experience with conditions in the field in which they operate, and combining this knowledge with such successes as will fall to their lot simply from the operation of the law of chances succeed in convincing some individuals in an uninformed public that there is virtue in their method. The danger of a false prophecy is, naturally, materially lessened when the "location" is made, as it usually is, in a region known to be generally underlain by abundant water. A prediction that water will be found anywhere in the central part of Antelope Valley is safe; hence success there should not be permitted to serve as a foundation for a reputation for occult powers on the part of a wielder of a forked twig. It is even conceivable that some assumptions as to depth to water might be correctly made by the locator if his knowledge of other wells in the region were at all complete.

The attempt to use the "witch" to locate oil in Antelope Valley resulted, as would be expected, in disastrous failure, since two wholly unsuccessful wells, which are stated to have cost over $20,000, were drilled on the advice of an operator of the implement.

INEXHAUSTIBILITY OF ARTESIAN SUPPLY.

The most generally accepted fallacy, and one which, unfortunately enough, is most harmful of all to the continued welfare of the Antelope Valley, assumes that because wells have flowed generously in the past and some are flowing even too abundantly during the present they may be expected to flow for all time, no matter how many are drilled or how much water is withdrawn from the underground reservoir. The acceptance of this theory has resulted in most of the injurious practices with reference to artesian water in the valley, and too much emphasis can not be given to the statement that the artesian supply is not inexhaustible, and that if the riotous waste of water is continued during future settlement of the valley, wells now flowing will have to be pumped, and the water level in many of the present pumping wells may be expected to fall below the limit of profitable lift.

PRESENT ECONOMIC DEVELOPMENT.

NUMBER OF WELLS.

Reference to the map (Pl. VI, in pocket) shows that wells have been sunk in greatest number along the southern margin of Antelope Valley, especially between Del Sur and the vicinity of Reid's ranch. In all more than 350 wells of all types were examined in the course of this investigation, and of these nearly 75 per cent are flowing.

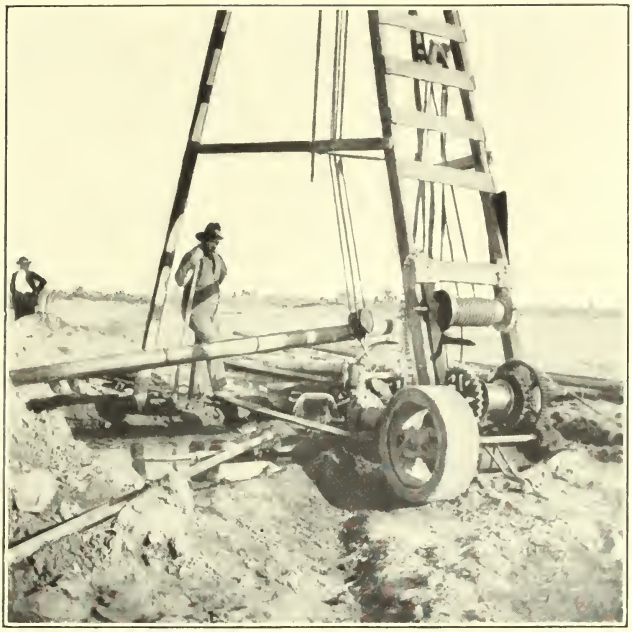
Although the sinking of wells in the valley began as long ago as the seventies, the most pronounced development has taken place in the last 15 years. Drillers reported in 1908–9 that indications were favorable to a very considerable increase in the number of wells, especially in and adjacent to the flowing area. The table on pages 70–89 gives condensed information regarding wells which were visited or concerning which data were obtained.

NONARTESIAN WELLS.

The shallower surface wells and, at the west end of the valley especially, some of considerable depth have been dug by hand. A well in which the soil and underlying beds prove of sufficient strength to "stand up" without lagging is considered ready for use when windmill and pump or other form of lift is installed at the surface. Judging from the number of caved-in surface wells, some of which are said to have obtained good water, this sort of construction for any except the shallowest wells is more expensive in the long run than that of a lined well. Shallow wells of the most satisfactory type, at least where the water tapped is in sufficient quantity, are those sunk according to artesian well methods—that is, by boring, casing, and perforating. Long buckets, adapted in diameter to the size of the well and furnished with inlet valves at the bottom, are used in such wells where the more effective methods of windmill or gas engine and pump have not been installed. The usual method of lift for nonartesian wells in the valley is the windmill, and because of the prevalence of winds during a great part of the year this is very satisfactory where the water is used only for domestic purposes and for stock. On the Dobey ranch, near Victorville, a double fan windmill raises water successfully from a depth of more than 300 feet, and this method should commend itself to settlers in Antelope Valley who are not in a position to install gas or steam pumping plants for deep nonartesian waters.

ARTESIAN WELLS.

The artesian wells of small bore, most of them less than 4 inches and some of them as little as 2 inches in diameter, sunk in the earlier days, were of little economic value, their purpose being usually only a step toward the obtaining of patents. In some places the depth



A. TYPE OF WELL-DRILLING RIG USED IN ANTELOPE VALLEY.

See page 63.

B. INSERTING PERFORATED CASING IN PARTLY COMPLETED ARTESIAN WELL.

See page 63.

to water is tested with small holes, but for actual use in irrigation wells 4 to 8 inches in diameter are most in favor, though there is at present a tendency toward the sinking of even larger holes. It is believed that except for pumping plants a diameter of 10 inches is about the maximum economical size where cost and serviceability are to be considered. Plate VII illustrates two phases of the drilling methods in common use in the region.

Earth reservoirs for storing artesian waters are used almost exclusively throughout the valley except where pumping plants have been installed. The greatest economy in the use of such plants is obtained by pumping the waters directly to the crops.

Reservoirs are usually constructed by dragging and tamping earth around the margin of the excavation from which it has been taken so as to form a levee 3 or 4 feet high. Most of these reservoirs are 40 to 200 feet long and about two-thirds as broad, with a depth of 5 or 6 feet in the central portion. Formerly wells were sunk in the center of such reservoirs, but, because of the difficulty of getting at them and the possibility of clogging, this practice has given way to the better one of placing the well near by outside the reservoir and constructing a short flume or ditch through which the water discharges into it. As a measure of protection against leakage and evaporation the levees are generally planted with willow or cottonwood trees.

PUMPING PLANTS.

The latest and the most scientific phase of water development in Antelope Valley is found in the use of pumping plants for irrigation. Not only are these plants installed on wells outside of the flowing area but even where a good flow exists, the yield of the flowing wells being thereby greatly increased and without permanent detriment, so far as known, to neighboring wells.

COST OF WELLS.

The cost and character of lift are briefly stated in the tabulated well data (pp. 70–89). Mr. M. J. Reynolds, of Lancaster, who has had large experience in well drilling in the valley, states that for average conditions the costs of drilling wells to a depth of 250 feet ranges from 60 cents per foot for a 4-inch well to 90 cents per foot for a 6-inch well, including casing.

EXAMPLES OF WELL DEVELOPMENT.

Post ranch.—The ranch belonging to Charles N. Post, of Chicago and Pasadena, includes the SE. ¼ sec. 10, T. 7 N., R. 13 W. It is one of several ranches which together are known as Esperanza, a settlement about 6 miles west of Lancaster. As it lies near the margin of the flowing area, it is comparatively free from alkali troubles and yet is

abundantly supplied with artesian water. The general arrangement of fields in this ranch is shown in figure 11; the fields planted to alfalfa have been irrigated from the adjacent reservoirs, but the larger of these fields is to be converted into a "cienaga pasture" by allowing the water from reservoir No. 3 to spread over it and keep the ground moist, thereby insuring the growth of natural grasses. It is proposed to plant a portion of the large oat field to alfalfa and to irrigate this from the pumping plant at the extreme northwest corner

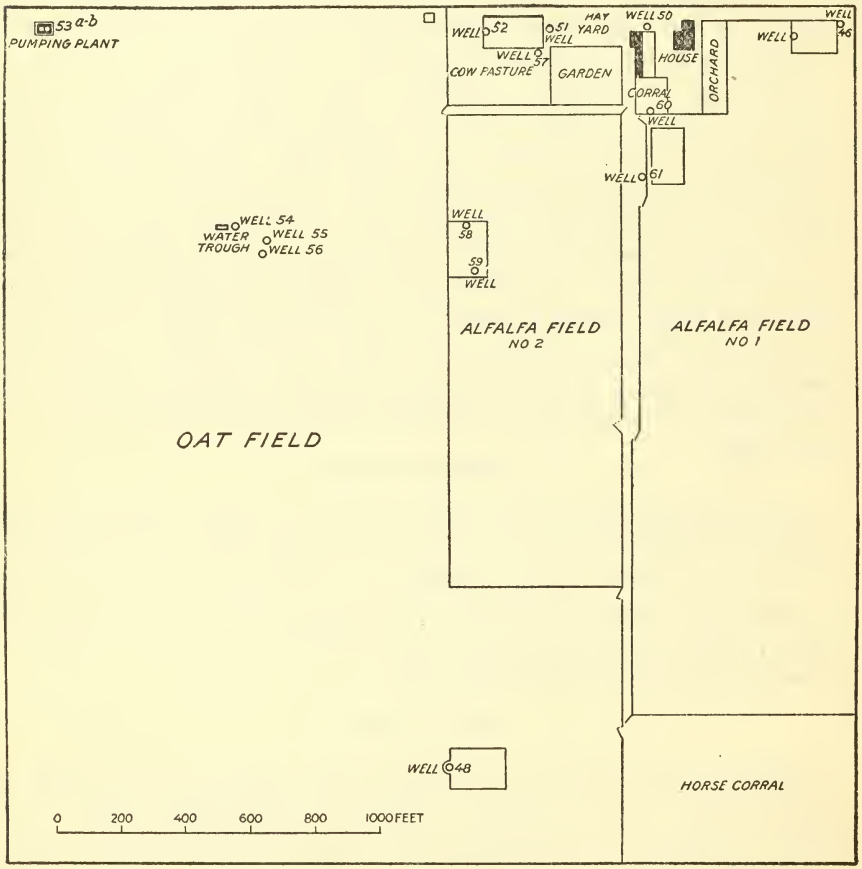


FIGURE 11.—Sketch map of Post ranch.

of the property. This plant comprises two adjoining wells sunk to depths of 275 and 418 feet, respectively, each of which yields flowing water. In the deeper well the upper flow, at about 275 feet, is cased off and only the water at 330 and 418 feet used. It is stated that the combined flow of these wells on completion was 40 miner's inches. A Byron-Jackson centrifugal pump No. 5 is connected with the wells, and this pump, worked by a 15-horsepower Fairbanks-Morse gas engine, throws a stream measured at 102.5 miner's inches. At pres-

ent 40 acres of alfalfa is irrigated by this plant. The total cost of the engine, wells, housing, and pump was $1,600.

Well No. 50 (table and map), which normally has only a slight flow, ceases entirely during the operation of the pumping plant. Its normal head is insufficient ordinarily to raise the water in a pipe more than a few feet above the ground, and to make it effective for domestic purposes a small windmill has been installed above it, and the water is lifted to a tank 19 feet above the surface.

Wells 54, 55, and 56 (see table) are used only for stock watering at present, as their flow, never very large, is insufficient for irrigation. A sample of water from well No. 51 on this ranch was taken for analysis, and the results obtained may be found in the table of analyses on page 57.

Marigold ranch.—Adjoining the Post ranch on the west is the Marigold ranch, which includes 160 acres in sec. 10, T. 7 N., R. 13 W. It belongs to George Marigold, of Los Angeles. Mr. W. Ohlson, manager of the ranch, states that the developments here represent work during the past three years only. Trees and hedges have been planted and substantial buildings well adapted to the needs of the region constructed.

The pumping plant consists of a Byron-Jackson centrifugal No. 5 and an 18-horsepower Western gas engine, which develops sufficient power to give a yield of between 150 and 170 miner's inches of water from two adjoining wells. One of these wells, 590 feet deep, flowed but 7 miner's inches originally, and the other, though artesian, had only sufficient head to bring the water to about 16 feet from the surface. The total cost of the wells and plant was $2,500. The distribution of crops on this ranch is unknown, but Mr. Ohlson states that 35 acres of alfalfa and 5 acres of onions, besides a number of young eucalyptus and other trees and garden truck, are irrigated.

Coleman.—The Coleman ranch, in sec. 20, T. 7 N., R. 12 W., is cited as an example of what may be accomplished, especially in the growing of alfalfa by careful, unremitting attention to the varying conditions governing profitable agriculture in Antelope Valley. The water is furnished by several flowing wells and a 509-foot artesian well (No. 177), over which a pumping plant, consisting of a 10-horsepower Sterns gas engine and a No. 5 centrifugal pump, has been installed. This plant is capable of increasing the yield of the well from about 8 to 40 miner's inches of water, which is used on alfalfa. Though the wells near this plant show the effect of pumping by the diminution of their flow, return to normal conditions follows soon after the plant is shut down. Well No. 178, about a quarter of a mile east of the plant, though it fluctuates seasonally, is not affected by the pumping.

Other ranches.—Other of the larger holdings in the flowing area of the valley belong to C. N. Reid, in sec. 10, T. 7 N., R. 11 W.; to the

Meadow Springs Land & Cattle Co.; in sec. 14, T. 7 N., R. 11 W.; to Oliver Miller, in sec. 6, T. 7 N., R. 11 W.; M. H. Cheney in sec 2, T. 7 N., R. 12 W.; and to others, the size of whose ranches is not available. Many small properties, particularly in the neighborhood of Lancaster, yield their quota of alfalfa and other produce, and a personal study of the methods employed in the use of water upon these tracts of small acreage will repay the intending settler.

ABUSE OF ARTESIAN RESOURCES.

Reference has already been made to the waste of artesian water in Antelope Valley and its effect on the pressure head which governs the flow. No figures are available which can give, even approximately, the total volume of water thus needlessly lost. At the time the field was visited 60 uncapped wells, flowing from 1 to 15 miner's inches each, were wasting 2,721,600 gallons per day, or an amount amply sufficient for the daily needs of a city of 25,000 people. At this rate the loss would amount to about 1,000,000,000 gallons of water per year. Aside from this gross misuse of the resource most essential to the continued prosperity of the valley, the waste is attended by several other results equally bad. After wells have been flowing without control for some time, even when much of the water has found fairly definite channels of escape, a large portion of the lands in the vicinity become water-soaked and sour. They are thus not only rendered infertile, but in some places they become so boggy that the miring of stock in them has become a mere commonplace instead of the basis for legal action against the lawbreaker who habitually leaves his wells uncapped. Waste is also a prime factor in causing the rise of alkali and in effecting its distribution over lands possibly otherwise cultivable; in this connection the recent poisoning of cattle as a result of drinking alkali-saturated surface water should be noted by stock owners. One well, No. 68 (table), in sec. 10, T. 8. N., R 12 W., about 3 miles south of Mr. Morgan's place, is a source of waste water which, though pure where it escapes from the ground, dissolves much alkali from the near-by flats. This well was visited by the writer, and he remembers the difficulty of driving along the boggy road and across the marshes which it has created during several years of uncontrolled flow. A conservative estimate places the waste from this well at 35,000,000 gallons per year. Well No. 256, which spouted vertically 8½ feet through a 1½ inch opening in a plug at the time it was visited, is located in sec. 12, T. 7 N., R. 13 W. This well is stated to have been uncapped almost since completion a number of years ago. A pool, formed around the well, is the source of a stream which flows toward the northeast for several miles and finally coalesces with the overflow from other wells to form sloughs and ponds of stagnant, strongly alkaline water.

This well was again visited on June 12, 1910, when it was found to be still uncapped, despite the warnings given during the preceding winter.

The California State law (L., 1877–78, p. 195) provides a remedy for this misuse of artesian wells. The attention of residents of the valley and local law officers is directed to the following sections:

> Any artesian well which is not capped or furnished with such mechanical appliances as will readily and effectively arrest and prevent the flow of water from such well is hereby declared to be a public nuisance. The owner, tenant, or occupant of the land upon which such well is situated who causes, permits, or suffers such public nuisance, or suffers or permits it to remain or continue, is guilty of a misdemeanor.

Also section 2, that—

> Any person owning, possessing, or occupying any land upon which is situated an artesian well who causes, suffers, or permits the water to unnecessarily flow from such well or go to waste is guilty of a misdemeanor.

For the purpose of this act an artesian well is defined (sec. 3) as "any artificial well the waters of which will flow continuously over the surface of the ground adjacent to such well at any season of the year;" and waste is defined (sec. 4) as follows:

> The causing, suffering, or permitting the waters flowing from such well to run into any river, creek, or other natural watercourse or channel, or into any bay, lake, or pond, or into any street, road, highway, or upon the land of any person other than that of the owner of such well, or upon the public lands of the United States or of the State of California, unless it be used thereon for the purposes and in the manner that it may be lawfully used upon the land of the owner of such well: *Provided*, That this section shall not be so construed as to prevent the use of such waters for the proper irrigation of trees standing along or upon the street, road, or highway, or for ornamental ponds, or for the propagation of fish.

A fine of not less than $10 or more than $50, together with the cost of prosecution, is assessed against those convicted of violating any of the provisions of this act, and the supervisors or roadmasters are empowered to enter upon the premises where wells complained of are situated and to institute action where violations of the provisions of this act are discovered.

FUTURE ECONOMIC DEVELOPMENT.

Antelope Valley has by no means reached the limit of development of its underground waters, but intending settlers and all others who have the interests of the region at heart must recognize its limitations in comparison with those of particularly favored regions in other parts of California.

The elevation and climatic conditions limit definitely the range of agricultural products to such crops as will grow in a temperate region of mild winters but hot summers. The products of the valley at present find a market in Los Angeles and the desert mining districts

to the north and northeast, and except as to a few special products, like almonds, pears, and apples, the valley competes with other producing areas in various parts of southern California.

One of the factors that agitates the settler whose aim is the agricultural development of the region has been the unrestricted ranging of cattle. This is a condition that is usual in regions that are passing from the period of development represented by the cattle and sheep industry to that represented by agriculture. Happily, a better understanding between the cattle owners and the agriculturists is already being brought about and a conciliatory attitude has been reached which would not have been possible a few years since.

One of the greatest drawbacks in the agricultural development of the Antelope Valley region is the alkali which occurs at and near the surface over large portions of the flowing area. This is a very common condition in areas of flow in arid and semiarid valleys in the West, and intending purchasers and settlers must be alert to its dangers. Certain of the lowlands of the valley are so alkaline that they can not be reclaimed; others, although alkaline, are cultivable with proper precautions; still other higher lands, chiefly outside the area of flow or near its borders, are free from injurious amounts of the alkaline salts. For the guidance of settlers and the protection of prospective investors there is urgent need of a systematic soil and alkali survey of the type made by the Bureau of Soils in the Department of Agriculture.

MAPS AND WELL DATA.

The map of Antelope Valley (Pl. VI, in pocket) indicates approximately, in addition to the general cultural and topographic features of the region, the distribution of the water-bearing and non water-bearing areas and the approximate outline of the flowing areas. The locations of most of the wells which had been sunk to January, 1909, inclusive, are shown. Nonflowing wells are indicated by an open circle, flowing wells by a solid dot, and pumping plants by a circle inclosing a solid dot when located over flowing wells and by two concentric open circles when over nonflowing wells. Each well is numbered, or where wells are too close together to be clearly indicated separately, a letter symbol is used upon the map and in the tables to indicate such groups. These numbers and letters refer to the table on pages 70–89, which gives essential facts of ownership, location, time of completion, class, depth, method of lift, cost, use, and total dissolved solids. As the temperature of the waters has a narrow range and does not indicate any particular condition of interest to the owner, it has been omitted from the table.

A map of Lancaster showing well locations in the town is also included with the report (p. 41).

The data upon which this table is based were collected by the author, with the very material assistance of owners and drillers throughout the valley. Especial thanks are due to Mr. M. J. Reynolds, whose systematic method of keeping records and logs of wells drilled during several years past and courtesy in making these available are greatly appreciated.

Wells of Antelope Valley region.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water[a] (feet).	Depth of well (feet).
1	James Barnes	Sec. 14, T. 8 N., R. 17 W.	1893	8-inch, bored	30	61
2	W. M. Fisher	Sec. 6, T. 8 N., R. 16 W.	.....	....do	94	(?)
3	Neenach School	Sec. 18, T. 8 N., R. 16 W.	1898?	Dug	200	210+
4	O. Caldwell	Sec. 10, T. 8 N., R. 16 W.	1894?	....do	200	200+
5	Southern Pacific	Sec. 15, T. 8 N., R. 16 W.	1895?	....do	40	60
6	Tom W. Gentry	Sec. 14, T. 8 N., R. 16 W.	.....	6-inch, bored	110	150
7	—— Arnold	Sec. 13, T. 8 N., R. 16 W.	.....	.....	.....	150
8	American Mexican Cattle Co.	Sec. 30, T. 9 N., R. 14 W.	1891	7-inch, bored	180	255
9	(?)	Sec. 6, T. 8 N., R. 14 W.	.....	5-inch, bored	140	190
10	(?)	Sec. 31, T. 8 N., R. 14 W.	.....	Bored	52	.....
11	A. A. Ullman	Sec. 36, T. 8 N., R. 15 W.	.....	.....	.....	210
12	Mrs. E. B. Potter	Sec. 10, T. 7 N., R. 14 W.	1881?	10-inch, bored	200	227
13a	F. D. Day	Sec. 6, T. 8 N., R. 13 W.	1908	7-inch, bored	60½	76
13b	....do	....do	1908	....do	60½	80
14	J. D. Gerblick	Sec. 16, T. 9 N., R. 13 W.	1904	7⅝-inch, bored	65	85
15a	E. M. Hamilton	Sec. 22, T. 9 N., R. 13 W.	1888	5-inch, bored	30	35
15b	....do	....do	1888	....do	20	35
16	S. O. Fowler	Sec. 14, T. 9 N., R. 13 W.	.....	.....	25	(?)
17	Home Mining Co	....do	1904	10-inch, bored	62	80
17a	Chas. A. Graves	....do	1904	Bored	71	84
18	Caliss Spencer	Sec. 24, T. 9 N., R. 13 W.	1908	7-inch, bored	33	56
19a	—— Bailey	Sec. 18, T. 9 N., R. 12 W.	1907	....do	32	155
19b	....do. (?)	....do	.....	Bored	3	75
20	F. R. Thomas	Sec. 14, T. 9 N., R. 14 W.	.....	....do	101½	103
21	J. F. Glasgow	Sec. 20, T. 9 N., R. 13 W.	1907	Dug, 3 by 4 feet	46	49
22	J. E. Johnson	Sec. 19, T. 7 N., R. 13 W.	1890	6-inch, bored	59	75
23	Frank Godde	Sec. 2, T. 6 N., R. 13 W.	1888	Dug	90	95
24	Wm. Strattman	Sec. 11, T. 6 N., R. 13 W.	1888	....do	100	110
25	Jake Ablutz	Sec. 34, T. 7 N., R. 13 W.	.....	Dug, 3 by 4 feet	99	.....
26	Los Angeles County.	Sec. 19, T. 7 N., R. 13 W.	1890?	Bored	53	54+
27	H. N. Smith	Sec. 18, T. 7 N., R. 13 W.	1898	....do	56	70
28	Mrs. M. H. Schiebler.	Sec. 20, T. 7 N., R. 13 W.	1890	3-inch, bored	.....	560S
29	Slater & Goldstein.	Sec. 17, T. 7 N., R. 13 W.	1890	6-inch, bored	30	300?
30	W. B. Nimmo	Sec. 13, T. 7 N., R. 14 W.	1885	....do	120	287
31	Mrs. —— Herbst.	Sec. 14, T. 7 N., R. 14 W.	1886	Bored	167	175
32	Alexander Macready.	Sec. 12, T. 7 N., R. 14 W.	1886	Dug, 4 by 3 feet	113	120
33	Mitchell & Johnson.	Sec. 1, T. 7 N., R. 14 W.	1889	13-inch, bored	105	113
34	Mrs. —— Jones	Sec. 2, T. 7 N., R. 14 W.	1886	7-inch, bored	160	187
35	George Marigold	Sec. 14, T. 7 N., R. 14 W.	1900?	5-inch, bored	120	160
36	—— Sanders (?)	Sec. 34, T. 8 N., R. 14 W.	1890	7-inch, bored	206	214
37	Dr. —— Manning.	Sec. 36, T. 8 N., R. 14 W.	1887	14-inch, bored	130	150
38	—— Handinger	Sec. 24, T. 8 N., R. 14 W.	.....	Dug, 4 by 4 feet	80	.....
39	Charley Smith	Sec. 26, T. 8 N., R. 14 W.	1886	7-inch, bored	120	140
40	Frank Geier	Sec. 15, T. 7 N., R. 14 W.	1885	....do	190	196
41a	W. Ohlson	Sec. 10, T. 7 N., R. 13 W.	1905	6⅝-inch, bored	16	590
41b	....do	....do	1906	....do	16	250
42a	R. Riddell	Sec. 2, T. 7 N., R. 13 W.	.....	6-inch, bored	.....	.....
42b	....do	....do	.....	3-inch, bored	.....	.....
42c	....do	....do	.....	....do	.....	.....
43a	Reese Snowden	Sec. 11, T. 7 N., R. 13 W.	1904	5-inch, bored	.....	.....
43b	....do	....do	....do	....do	370	380
43c	....do	....do	....do	....do	.....	.....
44	....do	....do	.....	8-inch, bored	.....	.....
45	Tot C. Alston	Sec. 11, T. 7 N., R. 13 W.	1898?	5-inch, bored	.....	400

[a] A=Artesian water at depth indicated.

[b] Quantities in miner's inches of 9 gallons per minute each, shown thus: R=original flow; S=stated flow; E=estimated flow; no letter=actual measured flow.

Wells of Antelope Valley region.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.[b]	Use of water.	Total solids (parts per million).	Remarks.
Wind			1½ inches S	Domestic	228	Log.
						Abandoned.
				Not used		Abandoned; log.
				do		Do.
				do		Do.
Wind			½ inch E	Domestic; stock.	268	
				Not used		Abandoned.
3½ h. p. gas			Ample	Stock	252	
				Not used		Do.
				Stock	286	In bedrock.
Wind				Domestic		
do				do	226	
8-foot windmill	$150.60	$100.00	10 inches S	Domestic; irrigation.	245	Log.
do	150.00	100.00	do	do	262	Do.
6 h. p. gas	300.00	450.00	20 inches E	Stamp mill		Do.
Wind			1.3 inches S	Domestic; cyanide plant.	274	
Steam pump			do	do	306	
Wind			2 inches S	Domestic; irrigation.	367±	Several similar wells on this place.
11 h. p. gas	75.00	1,125.00	2.8+inches S	Stamp mill		
10-foot windmill	117.60			Domestic; irrigation.		
Hand	34.40			Domestic	472	Log.
Steam pump	[c]2,000.00		100±inches S	Irrigation; stamp mill.		
Hand				Stock		
				do		
Hand	75.00	25.00	9,000 gallons pumped in 3 days by hand.	Domestic; irrigation.	270	
Centrifugal; 4 h. p. gas.	[d]113.00	425.00		Domestic		
10-foot windmill				do		
8+foot windmill			⅔ inch S	do		
Wind			Small	Schoolhouse		
8-foot windmill	50.00	150.00	1.2 inches S	Domestic		Do.
	500.00					Abandoned.
				Not used		
10-foot windmill			1.66 inches S	Domestic	261	
				Not used		Caved in; log.
				do		Do.
Wind				Domestic		Caved in.
Wind					251	
						Abandoned.
						Abandoned; caved in.
						Abandoned.
						Do.
				Not used		Dry at present.
Artesian and centrifugal; 18 h. p. gas.	2,500.00		150–170 inches	Irrigation	282	
Artesian (combined with 41a).					282	
Artesian					261	
do					303	
do						
do			7 inches	Irrigation		
do			2 inches R	do	290	
do				do		
do			6 inches	do	245	Temperature 81° F.
do			4+inches	do	272	

[c] Including plant.

[d] +Pipe.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
46	C. N. Post	Sec. 10, T. 9 N., R. 13 W.	1902	3½ inches inside diameter bored.	310	360
47a	J. W. LaForce	Sec. 15, T. 7 N., R. 13 W.	1894	Bored		250
47b	do	do	1896	do	263A	387?
47e	do	do	1896	do	290A	376
47c, 47d, 47f	do	do		do		
48	C. N. Post	Sec. 10, T. 7 N., R. 13 W.	1899	5 inches outside diameter, bored.	230	385
49	—— Hoyt	Sec. 14, T. 7 N., R. 13 W.		Bored		
A 50	C. N. Post	Sec. 10, T. 7 N., R. 13 W.				280
A 51	do	do	1902	4 inches outside diameter(?), bored.	310–360	360
A 52	do	do	1899	4 inches inside diameter, bored.		280
53a	do	do	1908	10-inch, bored	153+	275
53b	do	do	1908	8-inch, bored	330, 418	425
B 54	do	do		4 inches outside diameter, bored.	240	374
B 55	do	do		4-inch, bored	248–270	400
B 56	do	do			240–300	360
A 57	do	do		4 inches inside diameter, bored.	235–240+	280+
D 58	do	do		do	230	275
D 59	do	do		do	230	300
60a	L. S. Porter	Sec. 12, T. 7 N., R. 13 W.		4-inch, bored	10, 235, 250	340
60b	do	do	1905	do	250	540
61	Mrs. A. E. Lynn	Sec. 26, T. 9 N., R. 13 W.	1898	8 inches outside diameter, bored.	18–340A	404
62	Ella Kinton	Sec. 20, T. 9 N., R. 12 W.	1905	6⅝ inches outside diameter, bored.	9	183±
62a	do	do	1903	9 inches outside diameter, bored.	11	50
63	—— Patterson	Sec. 28, T. 9 N., R. 12 W.	1905	6-inch, bored	200A	240
64	W. B. Morgan	Sec. 22, T. 9 N., R. 12 W.	1905	do	115	140
65	do	do	1905	4½-inch, bored	240	500±
66	do	do	1905	4-inch, bored	7	329
67	P. B. Lampman	Sec. 2, T. 8 N., R. 12 W.	1904	4½ inches outside diameter, bored.	100	274
68	—— Lindermann	Sec. 10, T. 8 N., R. 12 W.	1904	do	110	164
69	E. M. Hamilton Hotel.	Sec. 21, T. 9 N., R. 12 W.	1905	6-inch, bored	15	100
70	Wm. Oliver	Sec. 32, T. 8 N., R. 10 W.	1907	do	7	612
71	do	do	1907	12½ inches inside diameter, bored.	11–12	91
72	John Demuth	do		12 inches outside diameter, bored.	11	103
73	Wm. Oliver	Location unknown		12-inch, bored	45	78
74	C. W. Roberts	Sec. 3, T. 7 N., R. 11 W.	1905	6 inches inside diameter bored.	12, 20A, 280A, 390–430A, 530A.	555
75	C. N. Reid	Sec. 10, T. 7 N., R. 11 W.		6-inch, bored		556
76	do	do		6 inches outside diameter, bored.	420	515
77	Dan Emmett	Sec. 12, T. 7 N., R. 11 W.	1906	6-inch, bored	22 surface water.	600
78	C. W. Davidson	Sec. 10, T. 7 N., R. 11 W.		do	399	532
79	C. N. Reid	Sec. 34, T. 8 N., R. 11 W.		5⅝ inches inside diameter, bored.	280	303
80	H. D. Davis	do			280	420
81a	Benedict Ray	Sec. 22, T. 8 N., R. 11 W.		3 inches outside diameter, bored.	227	235
81b	do	do		4 inches outside diameter, bored.	225	235
82	do	Sec. 20, T. 8 N., R. 11 W.				
83	Meadow Springs Land & Cattle Co.	Sec. 8, T. 7 N., R. 11 W.		5 inches outside diameter, bored.	25	58

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Artesian			14 inches R	Irrigation	290	
do	$117.40		3 inches E		284	Log of 47a, b, and e.
do						Exact data not available. Wells stated to have flowed total of 50 inches originally.
do			9 inches R			
do						
do	318.00		9+inches R; 1.7 inches now.		274	Log.
do				Not used	270±	Opens in reservoir.
Artesian; wind					271	
Artesian				Irrigation	283	Analysis.
do	168.00		8 inches R			Log; opens in reservoir.
Centrifugal on artesian.	1,600.00		40 inches R; pumps, 102.5 inches.	Irrigation		Log.
do	168.30		1 inch E	Stock	281	Do.
Artesian			1 inch	Irrigation	294	
do						
do			8 inches R			In reservoir.
do	160.00		6 inches R			Do.
do	180.00		2 inches R			Do.
do			17 inches A		299	
do			10 inches A		278	
Artesian; centrifugal; 8 h. p. gas.	393.25		30 inches S		283	Log.
Centrifugal; 10 h. p. gas.	113.00		25 inches	Not used		Do.
do	75.00	$500.00	12 inches S	do		Includes 3 wells close together.
Artesian	300.00		4 inches	Irrigation		Log.
do	140.00		7–8 inches S	do	237	Do.
do	400.00		1 inch	do	303	
Slightly artesian.				Not used		Log. Apparently reached bedrock.
Artesian	219.20		30–40 inches S; 27–30 inches.	Irrigation	249	3 feet to surface water.
do	123.00		10–12 inches S; 7 inches.	Stock	214	
Wind	100.00		1¼ inches	Domestic	351	
Hand; nonflowing artesian.				do	214	Does not quite flow.
Centrifugal; 15 h. p. steam.	170.00	725.00	15 inches	do		Water soft. Does not quite flow.
Centrifugal; 12 n. p. steam.	175.00		20 inches E	Not used		Does not quite flow.
(?)			Plenty			Not on map.
Artesian			11–12+ inches; 16 inches R.	Irrigation	233	Water used on 11 acres alfalfa.
Artesian and pumped.			60–70 inches pumped.		163	Upper water weak.
Artesian			8 inches R	Irrigation	167	
do			12.5 inches R	do	198	Contains a little sulphur.
Artesian (pumping plant).			4 inches R; 7 inches.	do	174	Log; pump discharge unknown.
do			8–10 inches S	do	158	
Artesian	336.00		6 inches E	Not used	167	
do			1½ inches R; 5 inches later.	Irrigation		Log.
do			6 inches	do		
(?)						Abandoned.
Wind				Domestic	178	

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
84	Dr. S. Worcester	Sec. 12, T. 7 N., R. 12 W.	1908	6 inches outside diameter, bored.	427–432	435
86	A. J. Renner	Sec. 14, T. 8 N., R. 13 W.	1907	do	30	200
87	do	do	1907	do	30	200
88	—— Stett	Sec. 2, T. 8 N., R. 13 W.	1908	do	7	330
89	—— Ingersoll	do	1908	do	7¾	300
90	C. N. Reid	Sec. 10, T. 7 N., R. 11 W.		4-inch, bored		500
91	—— Raffaelli	Sec. 32, T. 8 N., R. 11 W.	1907	6 inches outside diameter, bored.	Best 210	400
92	Mrs. —— Crane	Sec. 25, T. 8 N., R. 11 W.	1907	7 inches outside diameter, bored.		584
93	C. W. Hoehle	Sec. 18, T. 8 N., R. 10 W.	1907	6 inches outside diameter, bored.		608
94	Charles Corneliuson	Sec. 14, T. 8 N., R. 11 W.	1907	8 inches outside diameter, bored.		280
95	John Carter	Sec. 11, T. 7 N., R. 12 W.				
96	do	Sec. 10, T. 7 N., R. 12 W.		3 inches inside diameter, bored.		
97	do	do		3¼ inches inside diameter, bored.		
98	do	do				
99	do	Sec. 11, T. 7 N., R. 12 W.	1903	4⅜-inch, bored	265	334
100	do	do	1908	5⅝-inch, bored	380–440	500
101	A. J. Renner	Sec. 14, T. 7 N., R. 12 W.	1892	4-inch, bored	245	255
102	do	do	1906	6 inches outside diameter, bored.		548
103	do	do	1892	4 inches outside diameter, bored.	Surface water 22.	340
104	do	do	1892	4 inches inside diameter, bored.	240A	300
105	—— Renner, sr	Sec. 13, T. 7 N., R. 12 W.	1906	5⅝ inches inside diameter, bored.	260A	540
106	Andrew Watson	do	1905	4½ inches inside diameter, bored.	24 surface water; 280A.	580
107	—— Carter	do	1904	5⅝ inches, bored	240 A	365
108	—— Hart	Sec. 34, T. 9 N., R. 13 W.	1905	do	12-300 A	540
109	Carter Garfield	Sec. 30, T. 8 N., R. 12 W.		4½ inches inside diameter, bored.		
110	John Carter	Sec. 11, T. 7 N., R. 12 W.				
111	—— Johnson	Sec. 12, T. 7 N., R. 12 W.	1907	4 inches inside diameter, bored.	320–350	352
112a	M. H. Cheney	Sec. 2, T. 7 N., R. 12 W.			160–180	325
112b	do	do			290	340
112c	do	do			160–180	320
113	do	do	1908	5 inches, bored	19 surface water; 430 A.	500
114	do	do		4⅛ inches inside diameter, bored.		430
115	Reese Snowden	Sec. 11, T. 7 N., R. 13 W.	1896	3 inches outside diameter, bored.	240 A	535
116	do	do	1897	4 inches, stovepipe casing.	240 A	465
C 117	C. N. Post	Sec. 10, T. 7 N., R. 13 W.	1897	4 inches outside diameter, bored.		290
C 118	do	do	1902	3½ inches inside diameter, bored.		325
C 119	do	do	1894	4 inches inside diameter, bored.	247 A	256
120	Palmdale Hotel	Sec. 26, T. 6 N., R. 12 W.	1896	4 inches outside diameter, bored.	262	290
121	S. T. Cull	3½ miles NE. of West Palmdale.	1896	5 inches outside diameter, bored.	120	155
122	Mrs. —— Hazeltine.	Sec. 26, T. 7 N., R. 11 W.		6 inches, bored	56	64

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Artesian; pumping plant.	$478.50	.....	11 inches R; 40 inches pump.	Irrigation.....	.....	Water soft; log.
Nonflowing artesian.	220.00	.....	.....	Not used.....	.....	Water struck at 185 feet; log.
.....do.....	220.00	.....	.....	.....do.....	.....	Log.
.....do.....	363.00	.....	.....	.....do.....	.....	Surface water at 32 feet; log.
.....do.....	330.00	.....	.....	.....do.....	.....	Log.
Artesian.....	.....	.....	.....	Domestic.....	246	
.....do.....	440.00	.....	½ inch.....	Not used.....	.....	Do.
.....do.....	759.20	.....	.....do.....	.....do.....	.....	Water soft; log.
.....do.....	600.00	.....	20 inches S	.....	287	Log.
.....do.....	420.00	.....	3 inches S	Not used.....	.....	Do.
.....do.....	.....	.....	.....	.....	.....	
.....do.....	.....	.....	1½ inches.....	.....	182	
.....do.....	.....	.....	1½ inches E	.....	187	
.....	.....	.....	—1 inch.....	.....	174	
Artesian.....	112.00	.....	3 inches.....	.....	185	
.....do.....	.....	.....	5.5 inches.....	.....	154	Do.
.....do.....	.....	.....	12 inches R	Irrigation.....	.....	
.....do.....	300.00	.....	15 inches R; 13 inches.	.....do.....	185	Do.
.....do.....	.....	.....	.....	.....	.....	Do.
.....do.....	.....	.....	4 inches R; 3½ inches.	Irrigation.....	.....	Do.
.....do.....	.....	.....	.....	.....	.....	
.....do.....	.....	.....	8 inches S.....	Irrigation.....	184	
.....do.....	.....	.....	13 inches S.....	.....do.....	.....	
.....do.....	450.00	.....	.....	.....	.....	Water soft. Not used as yet.
.....do.....	.....	.....	15 inches E.....	.....	330±	
.....do.....	.....	.....	.....	.....	150	
Artesian; 4 h. p. gas, No. 2 centrifugal.	246.50	.....	2 inches.....	.....	156	
Artesian.....	.....	.....	{Combined flow of 20 inches S.	}	.....	
.....do.....	.....	.....			156	In reservoir.
.....do.....	.....	.....			.....	
.....do.....	500.00	.....	10 inches.....	Irrigation.....	169	Irrigates 14 acres.
.....do.....	.....	.....	5 inches.....	.....do.....	153	
.....do.....	267.50	.....	3 inches.....	.....	.....	Log.
.....do.....	.....	.....	12 inches.....	Irrigation.....	.....	Pump being installed.
.....do.....	203.00	.....	10 inches R.....	.....do.....	.....	Log.
.....do.....	.....	.....	4 inches S.....	.....do.....	.....	
.....do.....	192.00	.....	12 inches.....	.....do.....	.....	
10-foot windmill; 2½-inch pump.	525.00	.....	1.1 inches S.....	Domestic.....	259	Log.
Pumping plant..	.....	.....	.....	Stock and irrigation.	.....	Partial log; not on map.
.....	48.00	.....	.....	Not used.....	.....	

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
123	.....	Sec. 26, T. 7 N., R. 11 W.	.....	6 inches, bored..	60.....	69
124	J. C. Van Norden..	Sec. 20, T. 7 N., R. 11 W.	.....	4 inches, bored..	Surface water, 47; 450 A.	700
125	Sam Fletcher.....	Sec. 2, T. 7 N., R. 11 W.	1904	4½ inches outside diameter, bored.	261 A.....	504
126	Adney Estate.....	.....do.....	1897	4 inches outside diameter, bored.	Surface water, 15; 225A–294A.	431
127	.....do.....	.....do.....	1898	3 inches inside diameter, bored.	235.....	340
128	.....do.....	.....do.....	1899	4 inches inside diameter, bored.	375.....	400
129	Mrs. Eddy.....	Sec. 12, T. 7 N., R. 11 W.	.....	4 inches outside diameter, bored.	Surface water 17; 345 A.	380
130	—— Wolfenberger.	Sec. 18, T. 7 N., R. 11 W.	1905	Bored.....	Surface water 23; 253 A.	335
131	Oliver Miller.....	Sec. 6, T. 7 N., R. 11 W.	1903	6 inches, bored..	312.....	500+
132a 132b	.....do.....	.....do.....	.....	5 inches, bored..	306, 461.....	480
133	.....do.....	.....do.....	1905	4 inches outside diameter, bored.	240± A.....	441
133a	.....do.....	.....do.....	1905	.....do.....	240, 300, 375, 400..	530
134	Tilden Estate.....	.....do.....	(?)	? 4 inches inside diameter, bored.	11 surface water; 260 A.	400
135	.....do.....	.....do.....	1896	4 inches outside diameter, bored.	.....	320
136	Meadow Springs Land & Cattle Co.	Sec. 4, T. 7 N., R. 11 W.	1903	4¼ inches inside diameter, bored.	235.....	300±
137	.....do.....	Sec. 8, T. 7 N., R. 11 W.	.....	4 inches outside diameter, bored.	.....	.....
138	.....do.....	.....do.....	.....	10 inches, bored.	22 surface water.	51
139	.....do	.....do.....	1902?	4 inches outside diameter, bored.	235, 285, 290, 320..	460
140	.....do.....	.....do.....	1902?	.....do.....	435, 445.....	460
141	.....do.....	.....do.....	1902?	4¼ inches inside diameter, bored.	400.....	518
142	.....do.....	.....do.....	1903	4 inches inside diameter, bored.	.....	370
143	.....do.....	.....do.....	1903	.....do.....	.....	260
144	.....do.....	.....do.....	.....	5¾ inches inside diameter, bored.	230.....	460
145	.....do.....	.....do.....	.....	4 inches outside diameter, bored.	.....	330
146	Ben. W. Hahn.....	.....do.....	1899	5 inches outside diameter, bored.	235, 245, 280, 335..	350
147	Mrs. —— Story..	Sec. 6, T. 7 N., R. 10 W.	.....	3 inches inside diameter, bored.	16 surface water; 369 A.	430
148	—— Beadle.....	Sec. 18, T. 7 N., R 10 W.	....	7 inches, bored..	25.....	37
149	J. W. Wilkins.....	Sec. 31, T. 9 N., R. 12 W.	1897	4 inches outside diameter, bored.	45 surface water; 196 A.	259
150	George Miller.....	Sec. 8, T. 8 N., R. 12 W.	.....	.....	7 surface water; 271 A.	.....
151	—— Butterworth	.....do.....	.....	.....	.....	.....
152	Acme Cement & Plaster Co.	Sec. 26, T. 6 N., R. 12 W.	.....	Bored.....	379.....	400

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
.....	.....	.....	.....	.....	.....	Water rose 2 feet when struck.
Wind; nonflowing artesian.	.....	.....	.....	Stock.....	.....	Water within 5 feet of surface.
Artesian.....	$294.00	.....	7½ inches.....	.....	.....	Log.
....do.....	.....	.....	7 inches R	Irrigation.....	216	Do.
.....do.....	1,035.00	.....	3½ inches R	.....do.....	223	Cost of well exceptionally high.
.....do.....	.....	.....	1½ inches R	.....	234	Log.
.....do.....	285.00	.....	5 inches R	Irrigation.....	213	Log; now abandoned.
.....do.....	208.25	.....	3 inches R; 3½ inches.	.....	146	Log; contains slight sulphur.
.....do.....	275.00	.....	2½ inches R; 1¼ inches.	Domestic and irrigation.	198	Log.
.....do.....	.....	.....	.....	.....	318	Log; includes 2 wells.
Artesian; centrifugal, 8 h. p. gas.	.....	.....	.....	Irrigation.....	199	
.....	.....	.....	.....	.....do.....	199	Log.
Artesian.....	.....	.....	17 inches R; 4 or 5 inches.	Not used.....	211	Abandoned for cattle.
.....do.....	.....	.....	17 inches R; 7 inches.	.....	159	Log; abandoned.
.....do.....	.....	.....	7 inches R; 1½ inches.	.....	163	
Pumping plant..	.....	.....	.....	.....	.....	Data not available.
Centrifugal; 6 h. p. gas.	.....	.....	22 inches E	.....	.....	Nonartesian.
Artesian.....	.....	.....	.....	Irrigation.....	166	
.....do.....	.....	.....	2 inches E	.....	153	
.....do.....	275.00	.....	5½ inches R	Irrigation.....	169	No flow in summer.
.....do.....	225.00	.....	4½ inches R; 1+ inch.	.....	153	
.....do.....	.....	.....	2 inches R; −½ inch.	.....	162	
.....do.....	.....	.....	10 inches.....	Not used.....	166	Formerly for irrigation.
.....do.....	120.00	.....	4½ inches R.....	.....	.....	
.....do.....	193.00	.....	4 inches E.....	.....	161	Considerable odorless, colorless gas; analysis.
.....do.....	236.50	.....	3 inches R.....	Irrigation.....	246	Odor of sulphur; log.
6-inch pump and mill.	.....	.....	.....	.....	.....	Water rose 1 foot when struck. Plenty of water.
Doubtfully artesian.	.....	.....	.....	.....	.....	Log.
Artesian.....	.....	.....	3 inches R	.....	.....	Do.
.....do	.....	.....	.....	.....	.....	
15 h. p. gas.....	.....	[a] $3,000.00	9 inches.....	Manufacture of plaster.	223	Log.

[a] Estimated.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
153	W. M. Smith	Palmdale	1908	5 inches inside diameter, bored.	245	310
154	Southern Pacific R. R.	do		Bored		
155	Alpine Plaster Co.	do	1905	12 inches, bored	275, 355, 385	402
157	Dr. A. J. Garner	Sec. 2, T. 5 N., R. 12 W.		Dug	35	40
158	do	do	1906	do	38	42
159	Frank Ritter	do	1906	do	26	35
160	Southern Pacific R. R.	do		Dug 10 by 10 feet.	38	45
161	Jasper Lindsay	do	1908	10 inches, bored	6	22
162	do	do	1908	do	6+	80
163	—— Koch	Sec. 31, T. 6 N., R. 11 W.	1905	8 inches, bored	190	250
164	—— Butterworth	Sec. 7, T. 7 N., R. 9 W.		Bored		
165	—— Simpson	Sec. 34, T. 9 N., R. 10 W.		6 inches outside diameter, bored.	10, 31, 142A, 238A	240
166	Arthur Speaker	Sec. 18, T. 8 N., R. 10 W.	1908	6 inches outside diameter, bored.	230	235
167	E. C. Redman	Sec. 20, T. 8 N., R. 10 W.	1908	6 inches inside diameter, bored.	215	235
168	Pliny Finch	Sec. 8, T. 8 N., R. 10 W.		6 inches outside diameter, bored.	220	625
169	F. A. Bacon	Sec. 13, T. 8 N., R. 10 W.	1908	do	9 surface water; 250 A.	310
170	E. C. Redman	Sec. 20, T. 8 N., R. 10 W.		Bored	350	555
171	E. G. Bartlett	Sec. 10, T. 7 N., R. 11 W.	1906	6 inches outside diameter, bored.	200, 500	550
172		Sec. 4, T. 7 N., R. 11 W.				
173	C. N. Post	Sec. 10, T. 7 N., R. 13 W.	1903	4 inches outside diameter, bored.		376
174	H. J. Butterworth	Sec. 34, T. 8 N., R. 12 W.		4 inches inside diameter? bored.		269
175	C. N. Post	Sec. 10, T. 7 N., R. 13 W	1898	4 inches outside diameter, bored.	14, 42, surface water; 252, 313 A.	385
176	E. C. Coleman	Sec. 20, T. 7 N., R. 12 W.	1898	do	11 surface water; 132, 170, 227, 273, 332 A.	336
177	do	do	1903	5 inches outside diameter, bored.	300 A	509
178	do	do	1904	do		501
E 179	do	do		4 inches outside diameter, bored.	327	342
E 180	do	do	1898	do	11 surface water; 148 A.	155+
181	Lancaster Cemetery.	Sec. 15, T. 7 N., R. 12 W.	1903	Bored	280 A	410
182	M. H. Cheney	Sec. 2, T. 7 N., R. 12 W.	1900	4 inches inside diameter, bored.	15 surface water; 134, 189, 303 A.	314
183	—— Burns	Sec. 2, T. 7 N., R. 13 W.		4 inches outside diameter, bored.		302+
184	Lancaster Bakery.	Lancaster		do	128, 140	323
185	—— Porter	Sec. 12, T. 8 N., R. 12 W.	1904	do	137	262
186	B. F. Carter	Sec. 8, T. 7 N., R. 12 W.	1904	Bored	165 A, 22 A	268
187	"Desert Claims"	Sec. 2, T. 7 N., R. 12 W.	1890	4 inches outside diameter, bored.		267
188	R. J. Hotchkiss	Sec. 24, T. 7 N., R. 13 W.	1899	5 inches outside diameter, bored.		405

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
4 h. p. gas	$550.00			Domestic and stock.	238	Log.
Steam pump?				Domestic and depot.	249	
10 h. p. steam			1 inch		259	Log.
Hand				Not used		
do				Domestic	459	Raises 2 feet in winter.
6-foot windmill				Irrigation	476	
4 h. p. steam			7+ inches E	Supply for engines.	614	
Centrifugal; 13 h. p. gas.		$800.00	40 inches S	Irrigation		On San Andreas fault.
						Partial log.
Wind	500.00		5 inches	Domestic and stock.	211	Said to reach granite.
				Stock	500+	Includes 2 wells.
Artesian			50 inches R, 70 inches S, 40 inches E.	Not used	257	Log.
do	246.75		2 inches E			Log; pump installed.
do	246.75			Irrigation and domestic.		Partial log.
do	1,000.00		4+ inches	Irrigation	257—	
do	325.00		2 inches	Domestic		Log.
do			40 inches S, 20 inches actual.	Irrigation	217	
Artesian, centrifugal, 5½ h. p. gas.	550.00		12 inches flow	do	215	Pumps 35 inches.
				do	161	
Artesian				do		Log.
do			8 inches		197	Do.
do						Do.
do			5 inches		181	Do.
Artesian, No. 5 centrifugal, 10 h. p. steam.			40+ inches pumped.	Irrigation	211	
Artesian			12 inches R, 9 inches.	do	186	Log.
do			1 inch		206?	
do					206	Log.
do						Do.
do			5 inches		163	Do.
do			10 inches R			
do						Log.
do						
do				Not used	210	
do						
do			35 inches	Not used		Log.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
189a	C. I. Dunsmoore...	Sec. 16, T. 7 N., R. 12 W.	1904	Bored.....	7 surface water; 120, 135 A.	286
189b						
190	—— Doyle.....	Lancaster.....	1903?	.....do.....	18 surface water.	272?
191	Edwards & Gallagher.	Sec. 21, T. 7 N., R. 12 W.	1897	.....do.....	14 surface water; 93?, 184 A.	250
192	.....do.....	.....do.....	1897	4 inches outside diameter, bored.	111 A.....	405
193	Nick Evertswell...	Lancaster.....	1898	Bored.....	15 surface water; 155 A.	205
194	O. F. Goodrich....	.....do.....	1908	4 inches inside diameter, bored.	7 surface water..	177
195	Mrs.—— Hannah	Sec. 14, T. 7 N., R. 12 W.	.....	Bored.....	.....	340+
196	.....do.....	.....do.....	1902	4 inches outside diameter, bored.	228, 261 A	389
197	H. F. Keeler.....	Lancaster.....	1902	Bored.....	151, 268, 322 A....	405
198	....do.....	.....do.....	1902	.....do.....	.....	286
199	Lancaster.....	.....do.....	1898	4 inches outside diameter, bored.	4 inches outside diameter, bored.	411
200	Charles Forsyth...	Sec. 22, T. 9 N., R. 14 W.	1909	Bored.....	125.....	130
201	G. L. West.....	Sec. 22, T. 9 N., R. 14 W.	1909	.....do.....	120, 160 A.....	300
202	Lancaster School..	Lancaster.....	1904	4 inches outside diameter, bored.	138–155 first A; 240–267 second A; 298–304 third A; 367–393 fourth A.	411
203	—— Frye.....	Sec. 2, T. 9 N., R. 14 W	1909	6-inch auger.....	Dry.....	132
204	Henry Gummert..	.....do.....	1909	(?)	.....do.....	80
205	—— Myers.....	Sec. 24, T. 7 N., R. 12 W.	.....	6 inches outside diameter, bored.	47 surface water; 138, 155 A.	159
207	A. C. Noble.....	Sec. 22, T. 7 N., R. 12 W.	1895	Bored.....	516.....	567
208	.....do.....	.....do.....	.....	.....	.....	558?
209	.....do.....	.....do.....	1898	8 inches outside diameter, bored.	35 surface water; 82.	112
210	—— Protchard ..	Sec. 34, T. 7 N., R. 11 W	1898	Bored.....	16 surface water; 279 A.	564
211	.....do.....	.....do.....	.....	.....	8 surface water; 235 A.	403
212	J. K. Vance.....	Sec. 21, T. 7 N., R. 12 W.	1906	$4\frac{3}{4}$ inches inside diameter, bored.	10 surface water; 93, 124 A.	323
213	Jerome Rapelstein.	.....do.....	1907	6 inches outside diameter, bored.	70, 89, 164, 174, 206, 270, 324 A.	354
214	M. J. Reynolds....	Sec. 16, T. 7 N., R. 12 W.	1905	5-inch bored....	6 surface water; 81 A.	284
215	Joseph Reh.....	Sec. 21, T. 7 N., R. 12 W.	1907	6 inches outside diameter, bored.	.....	356
216	F. H. Robinson...	Lancaster.....	1902	3 inches spiral casing.	150, 235 A.....	272
217	.....do.....	Sec. 4, T. 7 N., R. 12 W.	1900?	.....	.....	257
218	T. V. Rockabrand.	Lancaster.....	.....	Bored.....	14 surface water; 265 A.	290
219	M. J. Reynolds....	Sec. 21, T. 7 N., R. 12 W.	1905	6 inches outside diameter, bored.	135?, 283 A.....	494
220	F. H. Robinson...	Lancaster.....	1904	4 inches outside diameter, bored.	125, 162 A.....	406
221	.....do.....	.....do.....	1902	3 inches inside diameter, bored.	230 A.....	265
222	.....do.....	.....do.....	.....	3 inches inside diameter.	235, 290 A.....	300

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Artesian						Log; in reservoir.
do						Log.
do						Do.
do						Do.
do						Do.
Artesian?						
Artesian						Locked; log.
do						Plugged; log.
Artesian; gas and centrifugal.			Pumps 20 – 25 inches.	Irrigation 5 acres	185±	Log.
Artesian						
do			12½ inches		190	Log.
			(?)	Domestic	(*a*)	16 feet gravel at bottom.
Nonflowing artesian.			Ample?		(*a*)	No water below 160 feet.
Artesian			1+ inch		208	Log.
Dry				Abandoned		Do.
Incomplete				Incomplete		Do.
Artesian						Location indefinite; log.
Gas engine				Not used		Log.
(?)						Not on map.
(?)						Log; not on map.
Nonflowing artesian.						Log.
do						Do.
Artesian	$258.40		12+ inches	Not used	205	Do.
do						
Artesian				Irrigation		
Artesian; 10 h. p. gas.	391.60	$600.00		do	188	
Artesian						Location uncertain; log.
do	115.65		16 inches R		208	Log.
do			4 inches E		191	Log; flow lowers at uncapping of adjacent wells.
do						Log; not on map.
do					208	Not on map.
do	84.00		6 inches R		210±	Do.
do			5 inches R			Do.

a Probably good.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
224	Jane Reynolds	Sec. 12, T. 7 N., R. 12 W.	1899	4 inches outside diameter, bored.	17 surface water; 250, 289 A.	430
225	Carl Schwab	Sec. 30, T. 8 N., R. 12 W.	.....	6 inches outside diameter, bored.	7 surface water; (?) A.	262
226a, 226b	Southern Pacific R. R. No. 1.	Lancaster	1899	4 inches outside diameter, bored.	13 surface water; 261, 273, 398 A.	402
227a	do	Cameron Station	1900	3 inches outside diameter, bored.	110	148
227b	do	do	1900	6-inch screw	.....	124
228	do	Oban; sec. 22, T. 8 N., R. 12 W.	1904	5 inches outside diameter, bored.	3 surface water; 221, 320 A.	371
229	Joe Taylor	Sec. 21, T. 7 N., R. 12 W.	1906?	4½ inches inside diameter, bored.	95, 142, 191 A	324
230	L. Tunneson	Lancaster	1906	.....	130, 207, 241, 343, 370, 380 A.	380+
231	M. J. Reynolds	do	.....	.....	.....	240?
232	—— Tunneson	Sec. 3, T. 7 N., R. 11 W.	1895	4 inches inside diameter, bored.	15, 27 surface water; 234, 391 A.	558
233	B. Chatt	Sec. 21, T. 7 N., R. 12 W.	1908	5 inches outside diameter, bored.	.....	317
234	Judge Melrose	Sec. 20, T. 7 N., R. 12 W.	1892	.....	50 A	64
F 235	Coleman, E. C.	do	1899	.....	125 A	125
F 236	do	do	.....	4-inch, bored	300 A	300
F 237	do	do	.....	.....	160 A?	100+
239	Nathan Cole, jr	Sec. 3, T. 5 N., R. 12 W.	(?)	Bored	20 surface water; 280 A.	282?
240	John H. Carter	Sec. 11, T. 7 N., R. 12 W.	1901–1903	Bored for oil	1,600 hot water A, ?, 1,800; warm water A.	2,000
E 241	E. C. Coleman	Sec. 20, T. 7 N., R. 12 W.	.....	3½ inches inside diameter, bored.	.....	.....
E 241a	do	do	1892	2½ inches inside diameter, bored.	125 A	125+
242	J. H. Carter	Sec. 10, T. 7 N., R. 12 W.	1901–1903	Bored for oil	500, 830, A warm water; 900 A.	1,100
244	.....	Sec. 20, T. 7 N., R. 12 W.	1905	4 inches outside diameter, bored.	500+ A	610
245a	A. W. Berry	do	1896	do	.....	.....
245b	do	do	1896	(?)	14 surface water; 155, 241, 320 A.	335
246a	A. E. Ladner	do	1896	3¾-inch, bored	.....	288
246b	do	do	1896	4-inch, bored	.....	335
247	—— Sibley	Sec. 23, T. 7 N., R. 13 W.	1893	7 inches inside diameter, bored.	.....	.....
248	Bowman & McCartney.	do	.....	.....	.....	.....
249	Mrs. Hartnett	Sec. 14, T. 7 N., R. 13 W.	.....	2⅛ inches inside diameter, bored.	220 A?	250
250	Dr. LaForce	Sec. 15, T. 7 N., R. 13 W.	.....	4 inches outside diameter, bored.	300 A	335
251	J. C. Hannah	Sec. (?) T. 7 N., R. 13 W.	.....	do	230	260
252	J. W. LaForce	Sec. 15, T. 7 N., R. 13 W.	1885	7 inches inside diameter, bored.	210 A	220
253	—— Vysette	Sec. 22, T. 7 N., R. 13 W.	1893	2¾-inch, bored	215 A	227

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Artesian			4½ inches		160	Log.
do			24½ inches		355	
Artesian, pumping plant.						2 wells; log.
						Not in Antelope Valley; logs.
Artesian			50 inches E	Engine water		Log; flows into high tank.
do			7 inches	Domestic	180	
do						
do						Log.
do			8 inches R			
do	$349.00		½+inch	Irrigation	193	
do			½ inch	Not used		
do			do	Domestic, dairy, and irrigation.	191	
do			2 inches			
do			1 inch			
do			Slight	Salt lick	(a)	
Artesian water (no oil).	10,000.00±		(?)	Nothing		Log and notes.
Artesian			2 inches			
do			¼ inch	Not used	182	No flow during pumping and use of other wells.
Artesian water (no oil).	10,000.00±		(?)	Nothing	210±	Log.
Artesian			17 inches S			
Artesian, pumping plant.			−8 inches S			Log.
Artesian, 5 h. p. steam, centrifugal No. 3.		$400.00	7 inches R		187	Log.
On 2 wells; artesian.			3¾ inches R		187	
Artesian			2 inches R; 1 inch.	Not used	248	
(?)						
Artesian			4 inches R; 1⅜ inches.		254	
do			2 inches		255	
do			Very slight		263	
do			12 inches		258	
do			4+ inches E	Stock	267	Analysis.

a Impure.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Depth of well (feet).
254	Mrs. Eva Porter...	Sec. 12, T. 7 N., R. 13 W.	1906	4¼ inches inside diameter, bored.	275? A.....	300
255	—— Weinmiller.	Sec. 4, T. 7 N., R. 12 W.	1892	Bored.....	.....	.....
256	H. D. Vreeland ...	Sec. 12, T. 7 N., R. 13 W.	.....	4 inches outside diameter, bored.	.....	.....
257	C. N. Post.....	Sec. 10, T. 7 N., R. 13 W.	.....	6 inches outside diameter, bored.	.....	.....
258	—— Freyendall.	Sec. 32, T. 8 N., R. 12 W.	.....	2-inch, bored....	.....	.....
259	.....do.....	.....do.....	1908	4¾ inches inside diameter, bored.	182 A.....	200+
260	Cyrus Wheeler.....	Sec. 34, T. 8 N., R. 12 W.	1895	4-inch, bored....	.....	275
261	L. A. Overton.....	Sec. 30, T. 9 N., R. 13 W.	1908	Dug.....	58 surface water.	62½
262	—— Duniway...	Sec. 24, T. 9 N., R. 14 W.	1908	6 inches outside diameter, bored.	73.....	402
263	Dr. Swartout.....	Sec. 18, T. 8 N., R. 12 W.	1908	6-inch, bored....	21 surface water; 62?, 371, 520 A.	560
264	Fairview Mining Co.	Sec. 24, T. 9 N., R. 13 W.	.....	5½ inches outside diameter, bored.	50?.....	(?)
265	John Mosby.....	Sec. 26, T. 9 N., R. 12 W.	1908	4 inches outside diameter, bored.	112, 155 A.....	165
266	Carl Blair.....	Sec. 26, T. 8 N., R. 12 W.	1908	.....do.....	147, 167 A.....	167
267	—— Simpson....	Rosamond.....	1886	6-inch, bored....	16 surface water.	30
268	John Stuckey.....	.....do.....	.....	.....	17 surface water.	34
269	Southern Pacific R. R.	.....do.....	.....	6-inch, bored....	.....do.....	30
270	S. J. Morford.....	Sec. 14, T. 8 N., R. 12 W.	1908	5 inches inside diameter, bored.	14 surface water; 100, 190, 270 A.	300
271	—— La Grande..	Sec. 22, T. 8 N., R. 12 W.	.....	4¼ inches inside diameter, bored.	.....	.....
272	J. F. Langston....	Sec. 2, T. 7 N., R. 12 W.	1906	.....	105, 365 A.....	369
273	—— Mellick.....	Sec. 28, T. 8 N., R. 12 W.	1890	Bored.....	.....	.....
274	(?).....	Sec. 4, T. 7 N., R. 12 W.	.....	.....	.....	.....
275a	F. B. Scates.....	Sec. 10. T. 7 N., R. 12 W.	.....	.....	.....	.....
275b	.....do.....	.....do.....	.....	.....	.....	.....
276a	Ward Place.....	.....do.....	.....	3 inches inside diameter, bored.	.....	.....
276b	.....do.....	.....do.....	.....	2 inches inside diameter, bored.	.....	.....
277	.....do.....	.....do.....	.....	4 inches inside diameter, bored.	.....	.....
278	.....do.....	.....	.....	Bored.....	.....	.....
279	John Carter.....	Sec. 10, T. 7 N., R. 12 W.	.....	.....	.....	.....
280	P. B. Matthison...	Sec. 34, T. 8 N., R. 12 W.	.....	4 inches outside diameter, bored.	230 A.....	265
281	C. N. Reid.....	Sec. 10, T. 7 N., R. 11 W.	1906	8 inches, bored..	653 A.....	659
282	—— Hogan.....	Sec. 22, T. 7 N., R. 11 W.	.....	5 inches inside diameter, bored.	322, 328.....	550
283	Mrs. A. J. Renner..	Sec. 14, T. 8 N., R. 13 W.	1906	5⅝ inches inside diameter, bored.	Water stands at 22.	420
284	G. M. Needham...	Sec. 28, T. 7 N., R. 12 W.	1908	4½ inches inside diameter, bored.	Water stands at 19.	700
285	Garfield Carter....	Sec. 30, T. 8 N., R. 12 W.	1906	4½ inches outside diameter, bored.	260.....	300

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Artesian			(?)	Not used	244	
do						
do			Large	Cattle		Great wastage.
do			5 inches R	Irrigation	226	
do			3 inches R	Domestic	218	
do	$140.00		6 inches R; 5½ inches.	Irrigation	218	
do	210.00					Log; location uncertain.
Wind				Domestic	252	
Pumping plant	500.00			Irrigation	323	Log; possibly artesian.
Artesian	300.00		10 inches	do		Soft water; log.
Hand					308	
Artesian	112.70		1½ inches	Irrigation	460	Analysis; contains sulphur.
do			15 inches S			
Hand				Domestic	438	
Windmill ?						Soft water.
Wind				Domestic and engines.	616	
Artesian	300.00		33 inches	Irrigation	330	Casing reduced to 4 inches; analysis and log.
do			26 inches	Not used	220	
do	370.00		45 inches E	Irrigation	186	Log.
do			11 inches E		206	
do			2 inches E			
do						
Artesian					203	
do					200	
do					257	
do					201	Includes 2 wells.
(?)						
Artesian	198.75		35 inches R; 35 inches S.			
do			22 inches R; 22 inches.	Never finished		
do						
Nonflowing artesian.	378.00			Not used		Water soft.
do	560.00					
Artesian	240.00		10 inches E			Location doubtful.

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet).	Dpth o well (eet).
286	John Brown Colony.	(?)	1896	4 inches outside diameter, bored.	27 surface water?.	382
287	—— Sakey	Sec. 14, T. 8 N., R. 11 W.		5½ inches outside diameter, bored.		
288	—— Hogan	Sec. 22, T. 7 N., R. 11 W.			42	
289	do	do		Bored	45	
290	W. P. Martin	Sec. 30, T. 8 N., R. 11 W.	1907	4 inches outside diameter, bored.	150	170
291	John Iseman	do		do	135–150	190
292	—— Wilcox	do	1904	2½ inches inside diameter, bored.		309
293	M. H. Cheney	Sec. 2, T. 7 N., R. 12 W.	1903	3½ inches inside diameter, bored.	250, 300 A	310
294	do	do	1902	do	150, 180 A	180
295	Capt. E. M. Heaton	Sec. 10, T. 7 N., R. 12 W.	1896	4 inches outside diameter, bored.	235, 265 A	270
296	do	do				175
297	E. O. Murray	Lancaster	1906	4 inches inside diameter, bored.	235, 240 A	293
298	—— Bachert	do	1883		450	450
299	—— Doyle	do				
300	C. H. Bachert	do				
301	D. S. Menzies	do	1896	3¾ inches inside diameter, bored.		
302	S. E. Heaton	do		Bored		
303	—— Carter, sr	do				
304	—— Carter	do				
305	do	do				
306	do	do				
307	L. Perez	do		4 inches inside diameter, bored.	7 surface water; 215 A.	308
308	B. F. Carter	do				
309	Mrs. Clara Kerr	do	1908		170 A	188
310	Mrs. —— Story	do	1907			160?
311	—— Reynolds	do	1896	3 inches outside diameter, bored.	220, 280 A	285
312	J. A. Varela	do	1897	4 inches inside diameter, bored.		180?
313	do	do	1897	3 inches inside diameter, bored.	160 A	275
314	do	do		2 inches inside diameter, bored.		150
315	A. V. Oldham	Sec. 9, T. 7 N., R. 12 W.	1905	4¼ inches inside diameter, bored.		
316	do			5⅝ inches inside diameter, bored.		
317	Wm. Radloff	Lancaster	1904	4 inches inside diameter, bored.	235–285	285
318	—— Ling			Dug	39	
319	Henry Brown	Sec. 21, T. 7 N., R. 12 W.				
320a	J. R. Robinson	Sec. 16, T. 7 N., R. 12 W.	1903	4½ inches outside diameter, bored.		350
320b	do	do	1905	do		250

Wells of Antelope Valley region—Continued.

Method of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
(?)				Not used		Not on map.
Artesian			1 inch		210	
Wind				Domestic and irrigation.	252	
Centrifugal?, 14 h. p. gas.			12+ inches E	Irrigation	221	
Artesian			2 inches	do	209	
do			3 inches	do	249	Log.
do			1¾ inches		178	Do.
do			14 inches	Irrigation	188	Irrigates 6½ acres alfalfa and 1 acre orchard.
do			2 inches R	do	203	
do	$175.00		8 inches R; 3.2 inches.	do	197	Log (see Lancaster map).
do			3 inches R; —1 inch.		198	
do	190.00		4½ inches	Irrigation	204	
do			2¾ inches R; 2¾ inches.		202	
do						
do				Domestic	190	
do			2 + inches	Domestic and irrigation.	194	Log.
do			1 inch	do	186	
do				Domestic		
do				do	203	
do					194	
do			4 inches			
do			5 inches R; 4½ inches.	Domestic	197	Log.
do						In small cement reservoir.
do			3 inches E	Domestic and irrigation.	198	
do			1½ inches		198	
do			5 inches R; 3 inches.		209	
do			—1 inch			
2½-inch centrifugal, 2½ h. p. gas.			— 3 inches	Irrigation	186	
Artesian						
do			22 inches E	Irrigation	205	
do			Good		199	
do			— 7 inches	Domestic	193	Not on map.
Wind				do	232	Do.
Artesian; centrifugal, 8 h.p. gas.						
Artesian	227.50		16 inches	Irrigation		
do	162.50		6 inches	do		

Wells of Antelope Valley region—Continued.

No. of well.	Owner.	Location.	Year completed.	Class of well.	Depth to water (feet.)	Depth of well (feet).
321	J. R. Robinson	Sec. 16, T. 7 N., R. 12 W.				
322	Mrs. —— Dahl	do				
323	George A. Lutz	do		3 inches inside diameter, bored.	100	135
324	W. P. Sears	do	1903		130, 180 A	250
325	George Lutz	do		3½ inches inside diameter, bored.		150
326	B. Rozenski	do		do		140
327	C. I. Dunsmoor	do				
329	—— Hamilton	Sec. 18, T. 7 N., R. 12 W.		4 inches outside diameter, bored.		270
330		do		3 inches inside diameter, bored.		
331	Lancaster School	Lancaster		4¼ inches inside diameter, bored.		600
332	do	do				
333	O. S. Buckley	do	1906	4 inches inside diameter.		287
334	—— Crocker	do				
335	Howard Jones	do	1902	3½ inches, bored		135
336	do	do		do		135
337	A. V. Oldham	do				
338	do	do				
339	H. D. Vreeland	do	1902	3½ inches inside diameter, bored.	120 A	150
340	do	do			120 A	160
341	Wm. Jones	do			170, 300	335
342	do	do			160 A?	170
343	—— Tunnison	do	1904	4 inches inside diameter, bored.	235 A	370
344	—— Vance	do		Driven		240
345		do				
346	Show?	do				
347	(?)	do				
348	—— Knecht	do				
349	(?)	do				
350	F. H. Robinson	do			290	300
351	do	do		Bored		
352	—— Adams	do	1896	4 inches outside diameter, bored.		291
353	T. V. Rockabrand	do	1896	3 inches outside diameter, bored.		264

Wells of Antelope Valley region—Continued.

ethod of lift.	Cost of well.	Cost of machinery.	Quantity of water available.	Use of water.	Total solids (parts per million).	Remarks.
Atesian			8 inches S		206	
.do			6 inches E		210	
.do			18 inches			
.do			14 inches R			
.do			7 inches		193	
.do			6½ inches S			
.do				Stock	198	
.do			½ inch E		219	Abandoned.
.do			Very slight		223	
.do			9 inches E			Not on map.
.do					279	Do.
.do			7 inches	Domestic and irrigation.	204	Do.
.do						Do.
.do				Irrigation	183	Do.
.do						Do.
.do						Do.
.do					223	Do.
.do	$97.55		4 inches E		182	Do.
Atesian, wind			− 3 inches			Do.
Atesian			4+ inches		200±	
.do			1 inch		200±	Not on map.
.do			7 inches R			Do.
.do			5 inches R			Do.
.do						New blacksmith shop; not on map.
.do						Not on map.
.do						Do.
.do						Do.
.do						Do.
.do			2 inches			Do.
.do	150.00		2½ inches R			Do.
.do			4 inches R			Do.
.do			(?)			Not on map, log.

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